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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Copenhagen:
West Denmark

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Volume 13

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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to

COPENHAGEN: WEST, DENMARK

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED ENERGY SYSTEM DESIGN PRACTICES

in October, 1977

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

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by

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PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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STATISTICAL SUMMARY

GENERAL

Name of plant	Vest Plant (West Plant)
Location of plant	Copenhagen, Denmark
Year completed	1970
Administrator	Communities of interest consist of several municipalities including parts of Copenhagen
Space of plant	approx. 120,000 m^2
Space of building	approx. 10,600 m^2
Cost of construction including a building	approx. 140,000,000 D.kr.

DESIGN DATA

Plant capacity	864 tonnes/24h Increased to 1152 in 1977 by addition of Furnace #4
Capacity, each furnace	288 tonnes/24h
Number of furnace	
Operating	3
Stand-by	0
Extension	1 + 2
Calorific value of refuse	
Lowest	1000 kcal/kg
Average	2000 kcal/kg
Highest	2500 kcal/kg

Composition of refuse	Lowest	Average	Highest
Combustibles	26%	45%	55%
Ash & Inerts	42%	26%	22%
Water	32%	29%	23%

Furnace temperature	
Minimum	850° C
Average	950° C
Maximum	1000° C
Contents of unburnt matter in residue	0 - 3%

STATISTICAL SUMMARY (Cont.)

OPERATION OF PLANT

Amount of refuse incinerated	220,000 - 330,000 tonnes/year
Cost of operation	D.Kr. 30/tonne of refuse
Number of operators and workers	45
Number of officers	10
Operating hours of plant	24 hours/day 7 days/week
Working hours of operators	8 hours/day 5 days/week
Number of shifts	6
Electric power consumption	1,000,000 KwH/month
Water consumption	8,000 tonnes/month
Actual continuous operating time	approx. 12 weeks
Actual operating days	365 days/year
Maintenance and repair of plant	
Regular or periodical overhaul & repair including mechanic, electric, and boiler systems	normal

REFUSE COLLECTION AND TRANSPORTATION

Population in refuse collection region of the plant	650,000
Area of refuse collection of the plant	325 km^2
Amount of refuse collected, presently	1400 - 2000 tonnes/day
Disposal of refuse	
Incineration	50%
Dumping at sea	0%
Reclamation	0%
Others (dump) industrial refuse	50%
Method of transportation	truck

STATISTICAL SUMMARY (Cont.)

Size of trucks	
Carrying capacity	refuse trans. 2 - 8 tonnes ash trans. 5 - 15 tonnes
Charge of collection	charged 30 D.Kr/t.
REFUSE STORING	
Weighing equipment of refuse	
Number	2
Type	automatic
Capacity	50 tonnes
Recording, printing, and summation of weight	automatic
Refuse silo (bunker)	
Number	1
Capacity	12,500 m^3
Dimension	
Length	56 m
Width	17 m
Depth	13.50 m
Specific weight of refuse	0.2 - 0.3 tonnes/m^3
Storing capacity	4 days max. refuse delivery
Refuse silo door	
Type	Flap, double-hinged
Number	12
Dimension	
Height	8.0 m
Width	3.8 m
Thickness, total	122 mm

STATISTICAL SUMMARY (Cont.)

Operation	hydraulic
Oozed water pit	
Capacity	13,000 m^3
Big refuse crusher	
Number	2 (in 1970 and 1975)
Type	Lindemann
Capacity	80 m^3/h
Location	Between unloading and refuse pits
Operation	hydraulic
Refuse feeding	Dumping from truck
FURNACE	
Filling hopper	
Number	1 per furnace
Clear opening at top	6500 mm x 6500 mm
Clear opening at bottom	2300 mm x 1150 mm
Height	5900 mm
Thickness of plate	8 mm
Materials	Mild steel
Volume	15 m^3
Filling chute	
Number	1
Clear opening	2350 mm x 1150 mm
Height	7000 mm
Thickness of plate	8 mm
Volume	19 m^3
Swivel gate in filling chute (damper)	
Number	1
Dimension	2300/2700 mm x 1260 mm
Thickness	10 mm
Operation	manual

STATISTICAL SUMMARY (Cont.)

GRATES

Grate I	
Width of grate	2700 mm
Length of grate	2500 mm
Area	6.75 m^2
Velocity of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	grate bar, grate plate
Materials of grate	
Grate frame	Meehanite HR
Grate bar or plate	Meehanite HR
Side seal	Nicromax
Grate II	
Width of grate	2700 mm
Length of grate	2000 mm
Area	5.4 m^2
Velocity of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	grate bar
Materials of grate	
Grate frame	Meehanite HR
Grate III	
Width of grate	2700 mm
Length of grate	5000 mm
Area	13.5 m^2
Velocity of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	grate bar, grate plate
Materials of grate	
Grate frame	Meehanite HR
Grate bar or plate	Meehanite HR
Side seal	Nicromax
Grate IV (None)	

STATISTICAL SUMMARY (Cont.)

Rotary kiln	
Shape	cylindrical
Diameter	
Inside of shell	4000 mm
Inside of lining	3400 mm
Length	8000 mm
Volume	73 m^3
Number of revolutions	0 - 12 rph
Inclination	3 deg.
Materials of shell	Carbon steel
Materials of support ring	High tensile strength steel castings
Materials of support roller	High tensile strength steel castings
Materials of thrust roller	High tensile strength steel castings
Number of support ring	2
Number of support roller	2
Number of thrust roller	1
Number of drive support roller	2
Steps between grates	
Number of steps	2
Height of steps between Grate I and Grate II	1.0 m
Height of steps between Grate II and Grate III	2.0 m
Steps between grate and rotary kiln	
Number of steps	1
Height of steps	1.0 m
Width of steps	2.7 m
Hopper under grate	
Number	4
Thickness of plate	6 mm
Size of chute	240 x 240 mm

STATISTICAL SUMMARY (Cont.)

Clinker chute	
Clear opening	900 mm x 1000 mm
Height	1900 mm
After combustion chamber	
Volume	125 m^3
Hydraulic equipment for grate movement and rotary kiln	
Number per furnace	1 set/furnace
Hydraulic pump	
Number per furnace	operating 2, stand-by 0
Capacity	47 lit/min. each pump
Pressure	75 kg/cm^2g
Motor	15 HP each
Oil tank	600 liters
Hydraulic cylinder	

	Grate I	Grate II	Grate III
Number	5	5	5
Cylinder bore	80 mm	80 mm	80 mm
Cylinder stroke	130 mm	130 mm	130 mm

Hydraulic motor for rotary kiln	
Number per kiln	2
Revolution	max. 1200 rpm
Torque	3 kg-m
Speed reduction equipment	
Type	Double Worm gear
Number per kiln	2
Revolution	max. 76 rph
Torque	1272 kg-m
Ratio of reduction	1:800

VENTILATING AND DRAFTING PLANT

Primary air fan (P. D. Fan)	
Manufacturer	Nordisk Ventilator
Number per furnace	1

STATISTICAL SUMMARY (Cont.)

Amount of air	45,000 Nm^3/h
Static pressure	230 mmAq
Temperature	30° C
Number of revolutions	1490 rpm
Driving	belt drive
Motor	75 HP
Secondary air fan (Cooling air fan)	
Number per furnace	1
Amount of air	35,000 Nm^3/h
Static pressure	460 mmAq
Temperature	30° C
Number of revolutions	1670 rpm
Driving	belt drive
Motor	150 HP
Flue gas fan (I.D. Fan)	
Number per furnace	1
Amount of gas	107,000 Nm^3/h
Static pressure	172 mmAq
Temperature	350° C
Number of revolutions	1010 rpm
Driving	belt drive
Motor	220 HP
Re-circulation fan	
Number per furnace	1
Amount of air	45,000 Nm^3/h
Static pressure	220 mmAq
Temperature	350° C
Number of revolutions	1460 rpm
Driving	belt drive
Motor	150 HP

STATISTICAL SUMMARY (Cont.)

CHIMNEY	
Chimney	
Type	Concrete with steel flue
Number	1 per 4 furnaces
Diameter at top	220 mm
Height	150 m
Gas velocity at top	max. 27 m/sec

Auxiliary Burning Plant for Furnace (None)

DUST COLLECTION PLANT	
Electrostatic precipitator	
Number per furnace	1
Capacity	107,000 Nm^3/h
Gas temperature	
Operating	300° C
Maximum	350° C
Dust content	
Inlet	7.5 g/Nm^3
Outlet	0.15 g/Nm^3
Efficiency	98%
Pressure drop	5 - 10 mmAq
Multi-cyclone (None)	

CLINKER AND FLY ASH TRANSPORTATION PLANT	
Clinker transportation equipment under clinker chute	
Type Clinker Sluice	skip-hoist
Number per furnace	1
Capacity	4 tonnes/h
Speed	7.8 m/min
Length of traveling	11 m

STATISTICAL SUMMARY (Cont.)

Ash transportation equipment under grates and rotary kiln	
Type	vibration conveyor
Number per furnace	1
Capacity	0.6 tonnes/h
Speed	.6 - 1.2 m/min
Width	diam. 300 mm
Length	16 m
Ash transportation equipment under boiler or gas cooler	
Type	vibration conveyor
Number per furnace	1
Capacity	0.6 tonnes/h
Speed	.6 - 1.2 m/min
Width	diam. 300 mm
Length	8 m
Fly ash transportation equipment under dust collector	
Type	(fluidizing)
Number per furnace	4
Capacity	0.6 tonnes/h
Clinker silo	
Capacity	1200 m^3
Dimension	
Length	47 m
Width	5.2 m
Depth	5 m
Specific weight of clinker	1.0 tonnes/m^3
Storing capacity	4 days
Clinker crane	
Number	operating 1 stand-by 1
Type of grab	Clam shell grab
Operation of grab	wire rope, hydraulic
Volume of grab	2.5 m^3
Weight of clinker held	2.0 tonnes
Weight of grab	2.1 tonnes

STATISTICAL SUMMARY (Cont.)

Weight of hoisting	4.1 tonnes
Span	9,630 mm
Length of traveling	48 m
Height of hoisting	12 m
Hoisting velocity	45 m/min
Traveling velocity	50 m/min
Traversing velocity	30 m/min
Hoisting motor	48 KW
Traveling motor	2 x 2.5 KW
Traversing motor	1.6 KW
Power supply system	Cable for main switch flexible hanging cable
Disposal of clinker and fly ash	landfill

GAS COOLING PLANT (BOILER)

Method of gas cooling	waste heat boiler
Boiler	
Type	hot water boiler water tube
Number per furnace	1
Design pressure	25 kg/cm^{2}g
Working pressure	16 kg/cm^{2}g
Steam or hot water temperature	170° C
Feed water temperature	140° C
Capacity	20 x 10^6 kcal/h
Heating surface (Units 1 - 3)	
Radiation heating surface	330 m^2
Convection heating surface	330 m^2
Superheater (None)	
Economizer	300 m^2
Gas air heater (None)	
Gas temperature	
Inlet	800° C
Outlet	280 - 320° C

STATISTICAL SUMMARY (Cont.)

Amount of gas	
Lowest calorific value	33,000 Nm^3/h
Average calorific value	77,000 Nm^3/h
Highest calorific value	98,500 Nm^3/h
Boiler outlet gas temperature control	yes, automatic
Heat utilization	district heating
Water spray gas cooler (None)	
Boiler cleaning equipment	
Type	shot cleaning
Soot blower (None)	
Hot water cooler	
Type	air cooler
Number	1
Heat exchanged	50 x 10^6 kcal/h
Steam or hot water pressure	16 kg/cm^2g
Steam or hot water temperature	
Inlet	170° C
Outlet	120° C

OVERALL SYSTEM SCHEMATIC

Several schematics are presented. Figure 15-1 shows the cross-sectional schematic and the overhead view. A more precise engineering drawing is shown in Figure 15-2.

COMMUNITY DESCRIPTION

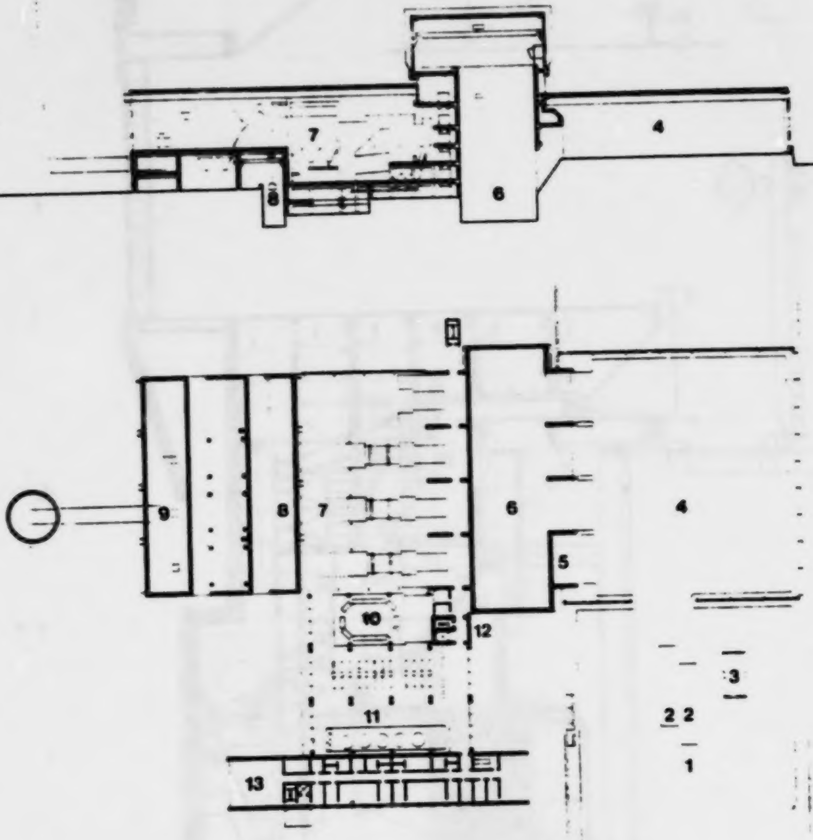
Geography

Figure 15-3 is a map of the Copenhagen metropolitan area. Copenhagen itself is located on the east coast of Denmark, not far from Sweden.

The West (Vest) refuse fired steam generator (Vestforbranding) is shown along with its twin unit on the Amager Island just southeast of downtown Copenhagen.

The terrain is rather flat, which is typical of eastern Denmark. There are no particular geographical features that impacted plant construction. The primary site location consideration was to be at the intersection of two main highways as shown in Figure 15-4.

The population in the City of Copenhagen proper has fallen from 550,000, ten years ago, to 430,000 presently. Reasons are typical of those in many large cities. Basically young families are moving to the suburbs, leaving the City for students, government workers, retired people, and those wishing a short commute to work. The West plant serves about 620,000 people in western Copenhagen and eleven of its western and northern suburbs.



1.	Opmarchplads	1.	Arrival
2.	Vægt	2.	Weighbridge
3.	Vægthus	3.	Weighing-station
4.	Aflæsningshal	4.	Unloading
5.	Knuser	5.	Crushing-mill
6.	Affaldssilo	6.	Refuse-pit
7.	Ovnhal	7.	Incineration-hall
8.	Slaggesilo	8.	Ash-pit
9.	Røgkanal	9.	Flue
10.	Kontrolrum	10.	Central control room
11.	Maskinsal	11.	Pump-room
12.	Trappetårn	12.	Staircase
13.	Administration, folkerum, værksteder	13.	Administration, staff-tract, workshops

FIGURE 15- 1. SIDE AND OVERVIEWS OF COPENHAGEN: WEST REFUSE-FIRED STEAM GENERATOR

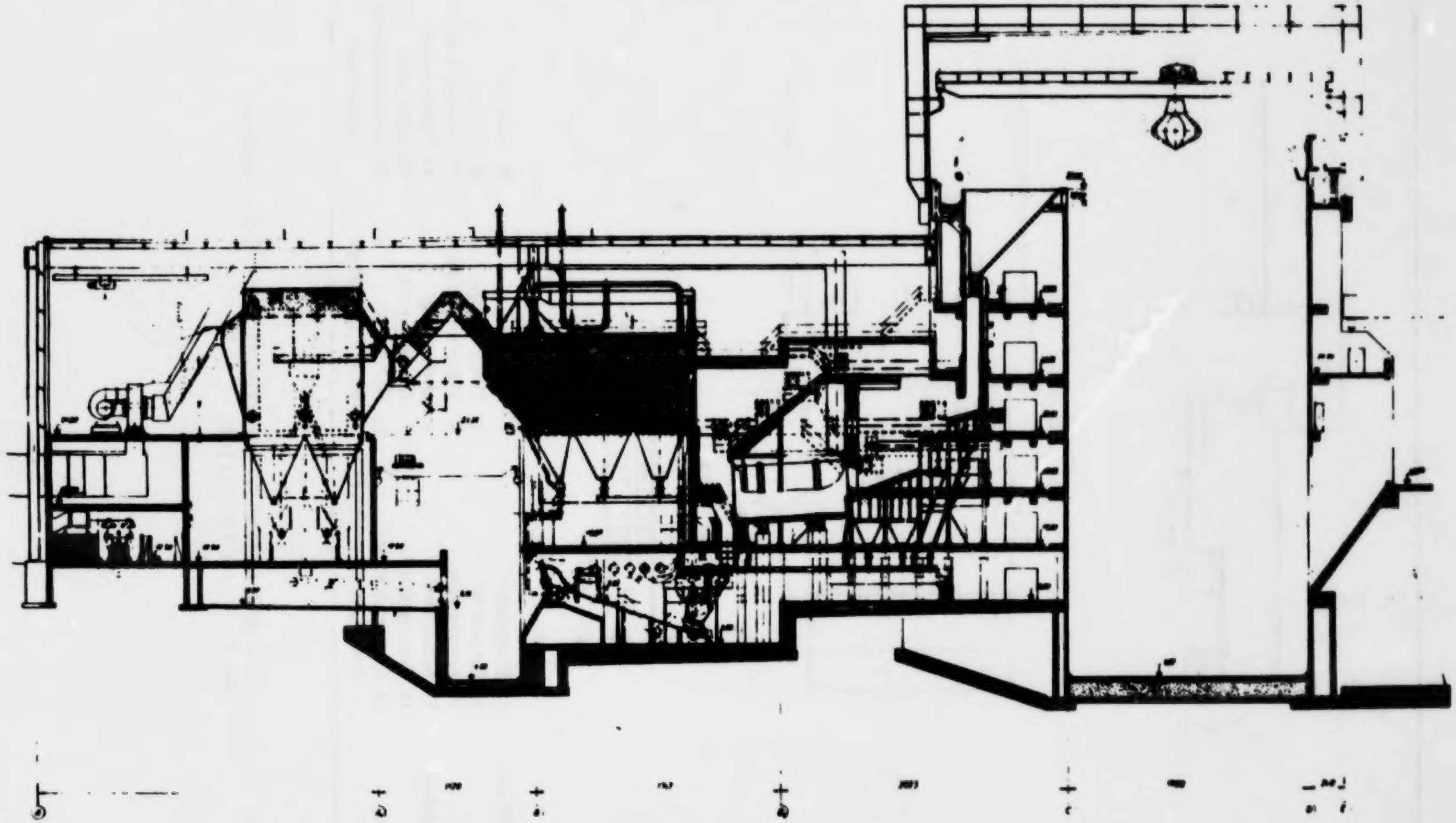
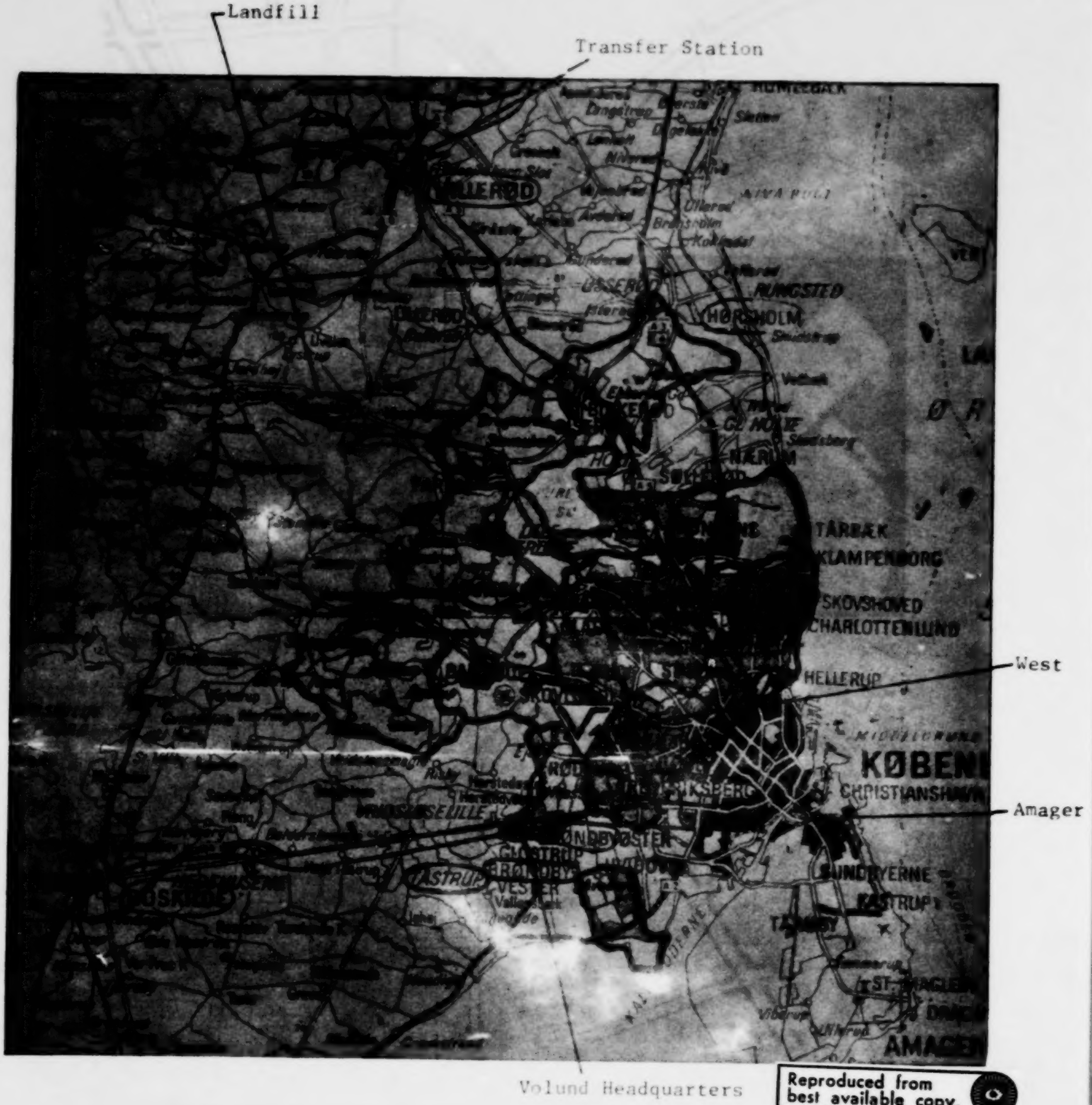


FIGURE 15-2. CROSS-SECTIONAL ENGINEERING DRAWING OF COPENHAGEN: WEST RFSG


Landfill
Transfer Station
HILLERØD
RUNGSTED
HØRSHOLM
NÆRUM
TÅRBÆK
KLAMPENBORG
SKOVSHOVED
CHARLOTTENLUND
HELLERUP
West
KØBEN
CHRISTIANSHAVN
Amager
FREDERIKSBERG
SUNDBYERNE
KASTRUP
TAASTRUP
ROSKILDE
AMAGER
Volund Headquarters

Reproduced from best available copy.

FIGURE 15-3. MAP OF GREATER COPENHAGEN AREA SHOWING THE LOCATION OF THE WEST (VEST) REFUSE FIRED STEAM GENERATOR, THE HILLERØD TRANSFER STATION, VOLUND HEADQUARTERS, ETC.

15 miles

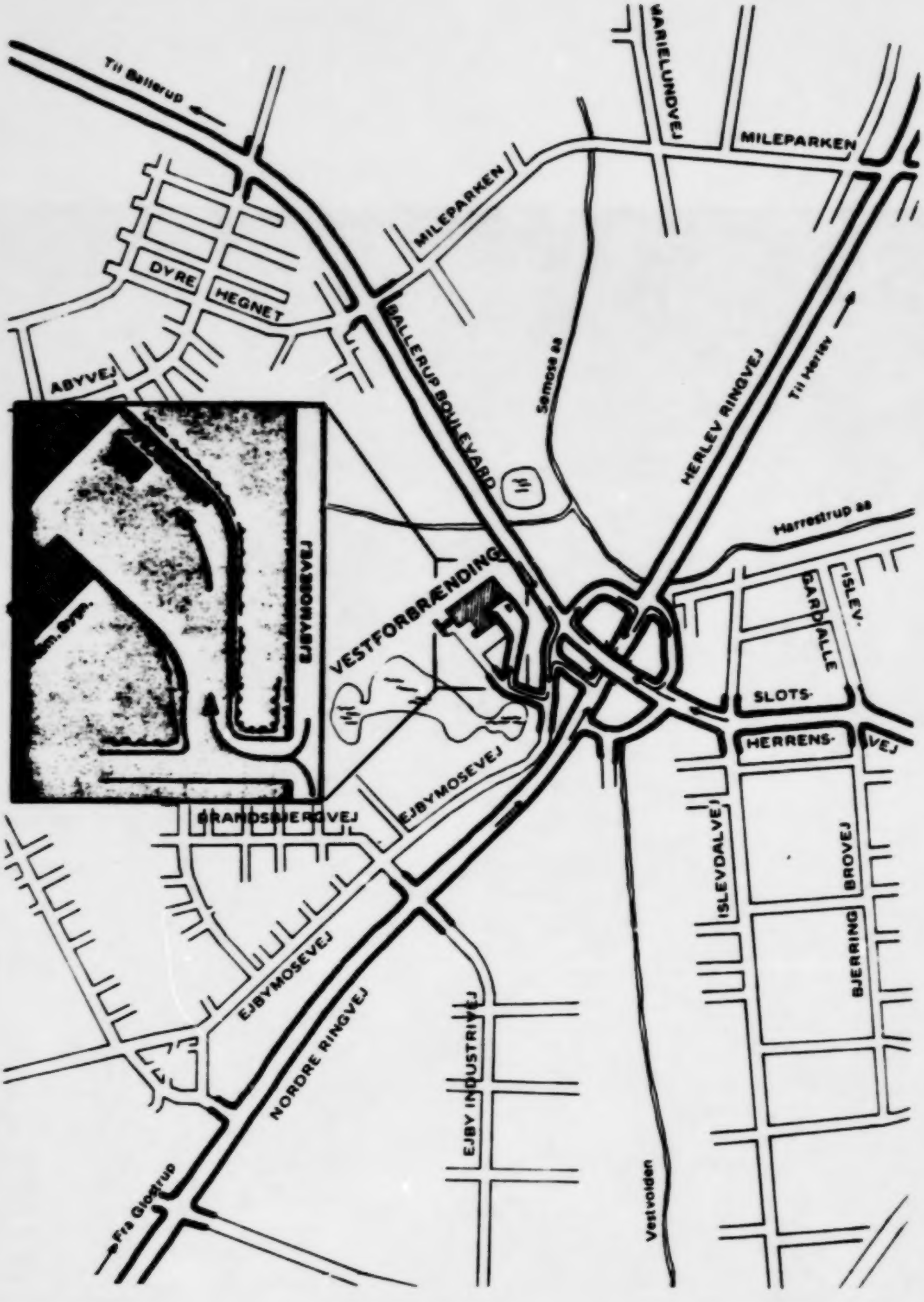

Til Ballerup
MARIELUNDVEJ
MILEPARKEN
MILEPARKEN
DYRE
HEGNET
BALLERUP BOULEVARD
ABYVEJ
Sømose aa
HERLEV RINGVEJ
Til Herlev
EJBYMOSEVEJ
VESTFORBRÆNDING
Harrestrup aa
GARDALLE
ISLEV
SLOTS-
HERRENS-
VEJ
BRANDSBJERGVEJ
EJBYMOSEVEJ
ISLEVDALVEJ
BROVEJ
BJERRING
EJBYMOSEVEJ
NORDRE RINGVEJ
EJBY INDUSTRIVEJ
Vestvolden
Fra Glostrup

FIGURE 15- 4 . DETAILED MAP SHOWING LOCATION OF WEST PLANT AT THE INTERSECTION OF TWO MAJOR HIGHWAYS

SOLID WASTE PRACTICES

Solid Waste Generation

The immediate Copenhagen metropolitan area, as served by the two large Volund plants (Amager and West), has a total population of 1,137,978 and generates 509,246 tonnes (560,171 tons) per year as shown in Table 15-1.

Twelve (12) communities (Figure 15-5) sent 255,807 tonnes (281,388 tons) to Copenhagen: West during the 1975/76 fiscal year. On a seven (7) day burning basis, about 479 tonnes (527 tons) per day were consumed. These figures compare with the rated capacity of 864 tonnes (950 tons).

Each person generates about 500 kg (1100 pounds) per year.

In summary, the refuse composition has been changing over the years to about these figures:

	1964/65	1970	1977
Heat Value (kcal/kg)	1,600	1,800 - 2,000	2,200
Moisture (%)	35	33	28
Combustibles (%)	40	45	49
Non-Combustibles (%)	25	22	23

Many years ago, 1964 and 1965, an extensive analysis was conducted over many months, seasons, weather conditions, and refuse generation sources. The results are summarized for April 1964 and January 1965. While the data is old, perhaps it will be useful. (See Table 15-2.)

Solid Waste Collection

In addition to the normal input from local garbage trucks, large transfer trailers from Hillerod travel about 40 km (25 miles) one-way to bring northern waste to the Copenhagen: West unit. Additional comments on collection activities are presented in the Copenhagen: Amager Trip Report 14.

The overall cost for collection and disposal averages about 420 D.kr. ($72.69) per year per person in Denmark.

TABLE 15-1. POPULATION AND REFUSE CONSUMPTION IN THE COPENHAGEN IMMEDIATE METROPOLITAN AREA

Population (inhabitants)	April 1, 1974	April 1, 1975	April 1, 1976
I/S Amager Area	524,955	580,556	568,343
I/S Vest* Area	581,333	575,996	569,635
	1,106,288	1,156,552	1,137,978
Refuse Consumption (tonnes)	1974-75	1975-76	1976-77
I/S Amager Plant	224,449	255,488	255,807
I/S Vest Plant	215,224	234,230	253,439
	439,673	489,718	509,246

*Vest is translated to West

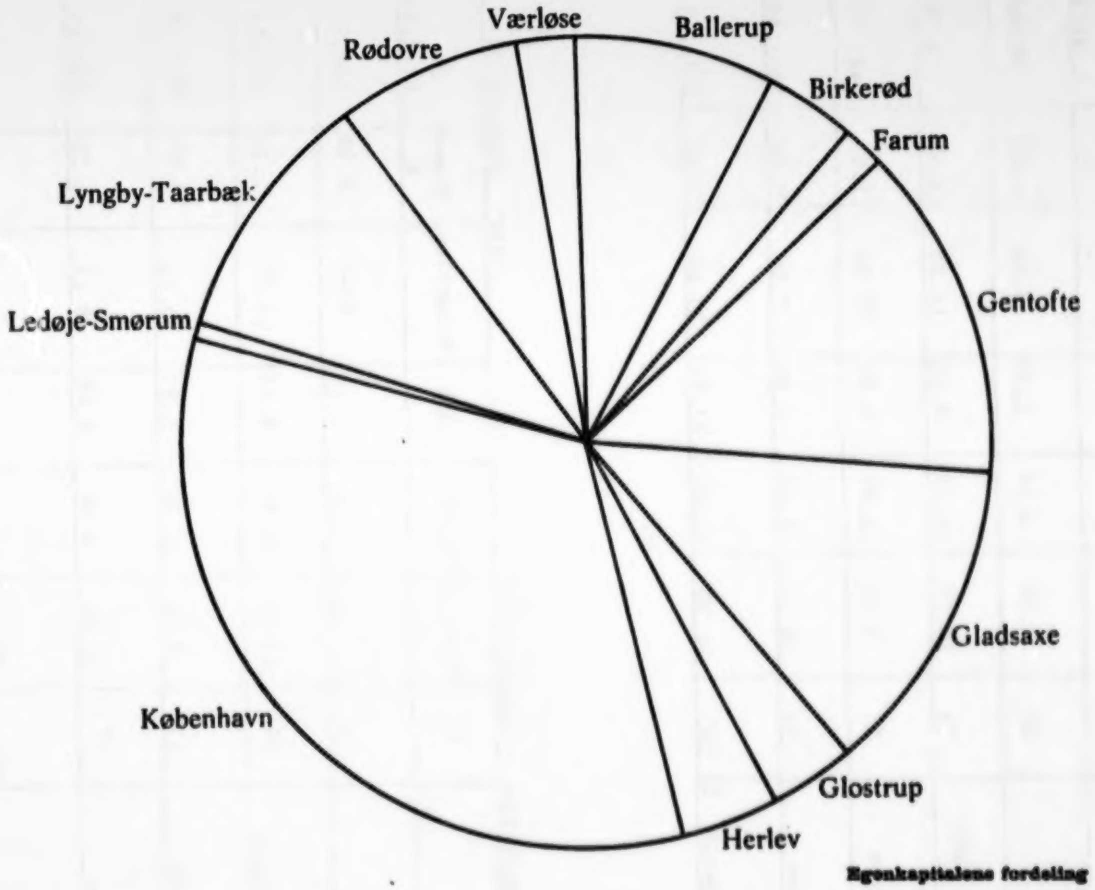


FIGURE 15-5. COMMUNITIES PROPORTION OF REFUSE INPUT TO COPENHAGEN: WEST RFSG

TABLE 15-2. REFUSE ANALYSIS FOR WEST INCINERATOR OF COPENHAGEN

Average Refuse Composition - Serie I Date: April 6 - 9, 1964

	%	Moist.	Comb.	Ash	Volatiles	Fixed C	Hi kcal/kg
1. Shoping Area	10	2.96	4.54	2.50	3.88	0.65	186.40
2. Villa Housing Area	34	10.06	14.68	9.25	11.24	3.45	528.76
3. New Housing Area	27	7.73	12.47	6.80	10.83	1.64	485.73
4. Industrial Area	29	10.35	9.27	9.39	7.69	1.58	366.56
Total Average on Serie 1	100	31.10	40.96	27.94	33.64	7.32	1621.45

Average refuse composition - Serie: III Date: January 11 - 14, 1965

	%	Moist.	Comb.	Ash	Volatiles	Fixed C	Hi kcal/kg
1. Shoping Area	10	3.18	4.06	2.77	3.47	0.58	166.90
2. Villa Housing Area	34	13.86	11.63	8.51	10.37	1.26	453.56
3. New Housing Area	27	9.07	12.60	5.33	10.94	1.66	511.38
4. Industrial Area	29	11.40	9.40	8.19	8.15	1.26	338.14
Total Average on Serie II	100	37.51	37.69	24.80	32.93	4.76	1,469.98

Solid Waste Transfer

The northern city of Hillerod has a transfer station as pictured in Figure 15-6 and located in the previous map, Figure 15-3. The one-way distance is 40 km (25 miles).

Recycling

The following Figure 15-7 shows a source separation truck discharging sorted items into several of the recycling bins placed near, but before the scale house. Thus, homeowners and businessmen who appreciate the need for recycling, and drive their own vehicles to Copenhagen: West, can also place their separated items into any of these several containers.

Solid Waste Disposal

Including demolition debris and household refuse, about half is incinerated and half is landfilled northwest of Copenhagen and near Uggelose. Negligible amounts of refuse are recycled.

Since the Number 4 Unit began operation in 1977, the landfill has adopted the policy of charging more money for combustible loads than non-combustible loads. Of the ash produced by West, 90% is recycled. The remaining 10% or 10,000 tonnes (11,000 tons) is landfilled at Uggelose 12 km (7.5 miles) away.

The greater Copenhagen metropolitan area is now served by eight (8) refuse fired energy plants: some are shown in the previous map, Figure 15-3. All of the following are within a 32 km (20 miles) semi-circle radius of Copenhagen:

Vest (West)
Amager
Brondby
Taastrup
Roskilde
Albertslund
Horsholm
Helsinor

FIGURE 15-6 . UPPER PORTION OF TRANSFER STATION AT HILLERØD

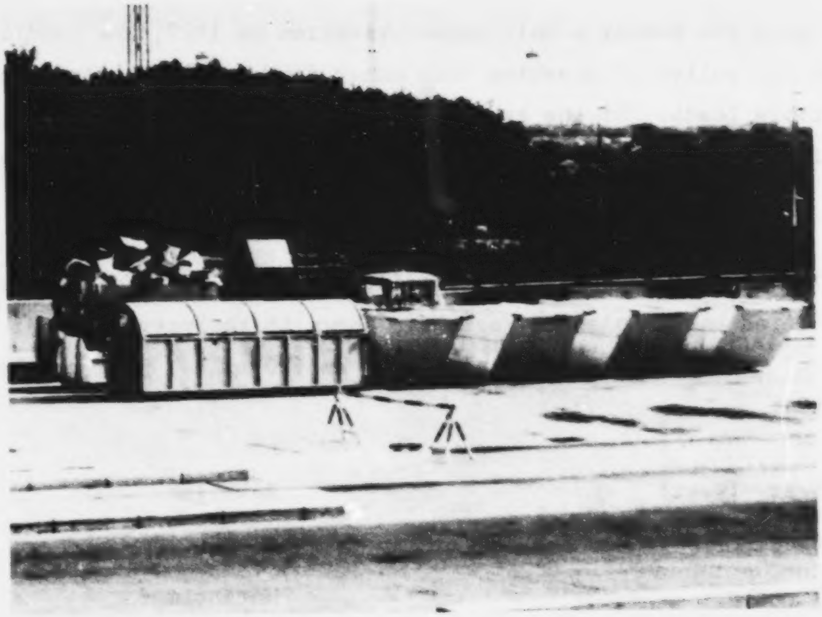


FIGURE 15- 7 . SOURCE SEPARATION TRUCK DISCHARGING SEPARATED ITEMS INTO RECYCLING BINS BEFORE SCALES AND TIPPING FLOOR AT COPENHAGEN: WEST

DEVELOPMENT OF THE SYSTEM

History

Waste-to-energy began in Copenhagen in the early 1930's with the 1932 commissioning of Gentofte two 144-tonne (158 ton) per day Volund grate/rotary kiln furnaces, each with a three drum boiler as shown in Figure 15-8. The steam was used to make electricity as specified by the City's Electrical Board. This construction was followed by two similar Volund units at Frederiksberg in 1934.

These two plants, see Figure 15-3 for location, served Copenhagen well for forty years. During that time these plants had reached their capacity and excess refuse had to be landfilled both inland and on the sea coast. Referring back to the map, Figure 15 - 3, notice the large undeveloped area in the western part of Amager Island. This was basically low swamp land that has been filled in with both demolition debris and household refuse.

During the 1960's, when knowledge of landfill leachate damages became better known, and when neighbors became upset over blowing trash, etc., local citizens groups on Amager Island were effective in getting the attention of elected officials. Details are explained in Trip Report 14 that discusses Copenhagen: Amager. One reason for mentioning it in this report is that the excitement about Amager encouraged the residents west of Copenhagen to develop a similar system.

Excerpts from a locally provided summary comments about the motivation for development.

"The need for a permanent solution to the refuse problems of these municipalities made the foundation of the West Incinerator.

The possibility of dumping refuse in the open was not any more feasible in the densly populated area.

These municipalities, therefore, had a common need in spite of different structures in both population, trade and politics. This need the municipalities sought to meet by mutual cooperation.

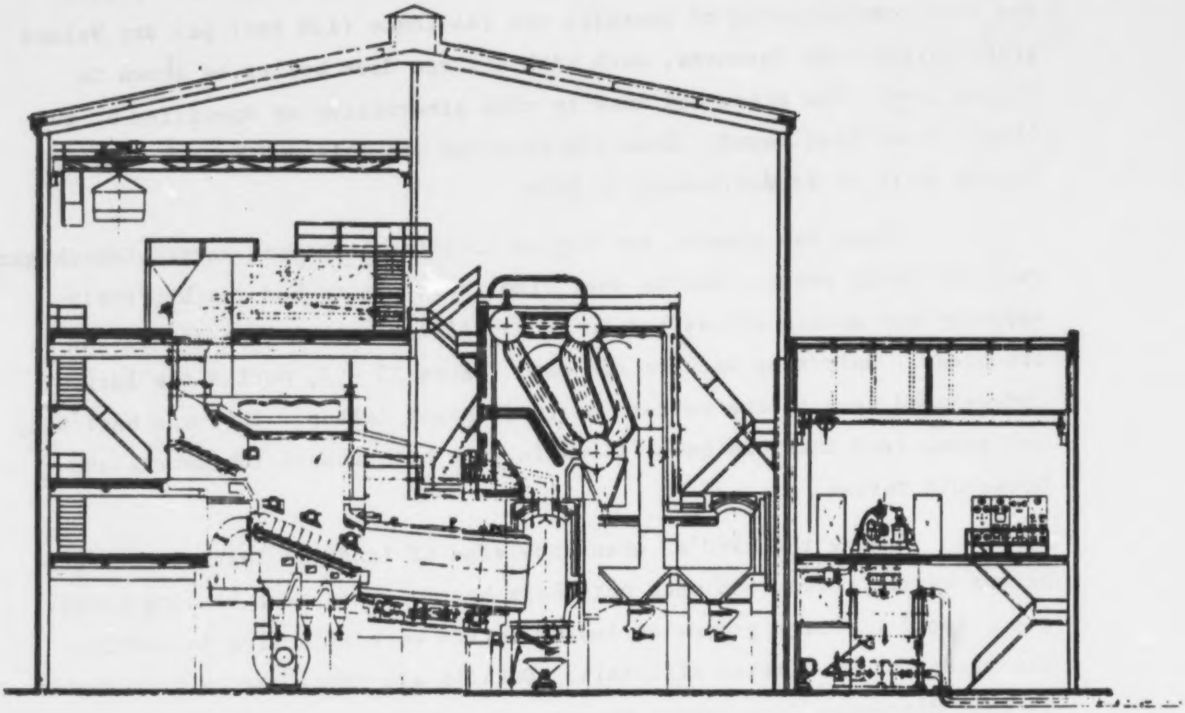


FIGURE 15-8. FIRST VOLUND SYSTEM BUILT AT GENTOFTE IN 1932 AND DECOMISSIONED 40 YEARS LATER IN 1972

The transport of the refuse continued to be the job of the municipalities on the principle that this problem very well could be solved locally and that the small truck firms had a better contact with both the local political councils and the community to be served.

Hereafter the cooperation was concentrated on this (i.e. the agreed objective was twofold): To reduce the volume of refuse as much as possible, due to the demands to dumping, and at the same time the municipalities wanted to exploit any heat energy in the refuse.

Then the decision to build an incinerator plant was made, situated so that it was placed centrally in relation to all the partnership municipalities, with attention to driving distances.

The regulation therefore stipulates a condition, that the municipalities shall establish an arrangement for payment of transport so that municipalities with the shortest driving distance contribute an amount to the municipalities with longer driving distance, in order to obtain equal economy in transport.

The following types of refuse are treated:

Domestic Refuse
Garden Waste
Large-size Waste, such as Furniture
Industrial Refuse
Sludge from Treatment Plants

The joint community will further seek to assist other municipalities with other types of refuse so far as it is possible within the environmental laws.

The weighed-in amounts of refuse correspond to between 280 and 350 kgs per inhabitant per year. However, not actually giving the exact amount per inhabitant in this area.

Since delivery of solid refuse is not compulsory the total amounts cannot be made up, because still a good deal of refuse is taken to dumping places.

It is forseen that the joint community will seek to establish a place for discarded items within the area, to be arranged according to the enviromental laws.
This discarding area is to supplement the incinerator plant in total refuse treatment for the 12 municipalities".

The other reason for mentioning Amager in the West (Vest) trip report is that Volund's competitive approach was to provide both organizations with a quantity discount if both purchased similar units.

The competitors at West were:

Heenan-Froud
Martin
VKW
Volund
Von Roll

Officials remember that VKW, Volund, and Von Roll had the lowest single unit prices (i.e. non quantity discount). Other excellent Volund plants in Denmark, the long history of successful operations at Gentofte and Frederiksberg, the low (maybe not the lowest) single plant price, the quantity discount, and the Volund headquarters being nearby all contributed to the decision favoring Volund.

Copenhagen: West is owned by the twelve communities, it serves, as are listed in the Organization Section at the end of this trip report. West started operations in November 1970 with three 12 tonne (13.2 ton) per hour furnaces assuming 2,500 Kcal/kg. Later in 1977, a fourth furnace rated at 14 tonne (15.4 ton) per hour, assuming 2,500 kcal/kg, was installed.

Comment:

> Many of the more precise interviewees refer to "xx tonnes per hour assuming y,yyy kcal/kg." After all, the limiting factor is not how much refuse can mechanically be pushed through the unit. Rather, the limiting factor is the heat release rate that will not unduly affect system reliability.

Future Planning of Refuse to Energy Capacity

A study, see Table 15-3 and Figure 15-9 , of refuse quantities in the future was made in order to ascertain when more furnaces would be required. With this knowledge, a financial plan (including surcharge) was implemented to allow for accumulation of funds thus avoiding large loans at high interest rates.

The development was not quite according to the plan which called for Unit #4 to be added in 1972. Population expansion has not been as rapid as anticipated. (See Table 15-3). West purchased a furnace unit in 1976 and is now considering a scheme with RDF. The surplus of paper, plastic and wood contained in the refuse at the collecting source in the summer time will be pelletized to fire in specially designed boilers in the winter time, when there is more need for the heat in the district heating system.

Joint Cooperation of the Municipalities on Research and Future Forms of Refuse Treatment

Clinkers (Ash)

The incinerator plant produces approximately 50,000 to 60,000 tons of clinkers per year and this amount is landfilled according to environmental requirements in cooperation with the State Forestry Department.

Other Methods of Refuse Treatment

The joint community of West Incinerator examines on behalf of all partnership municipalities whether other methods of refuse treatment ahve been developed, which in cooperation with the incinerator plant can provide the municipalities with better environment and better method for the society. Figure 15-10 is an example of this total resources management philosphy.

The Future of Refuse Treatment

The joint community of West Incinerator is in charge, on behalf of the municipalities, of continual examinations of the future refuse treatment and the demands by the society to the muncipalities.

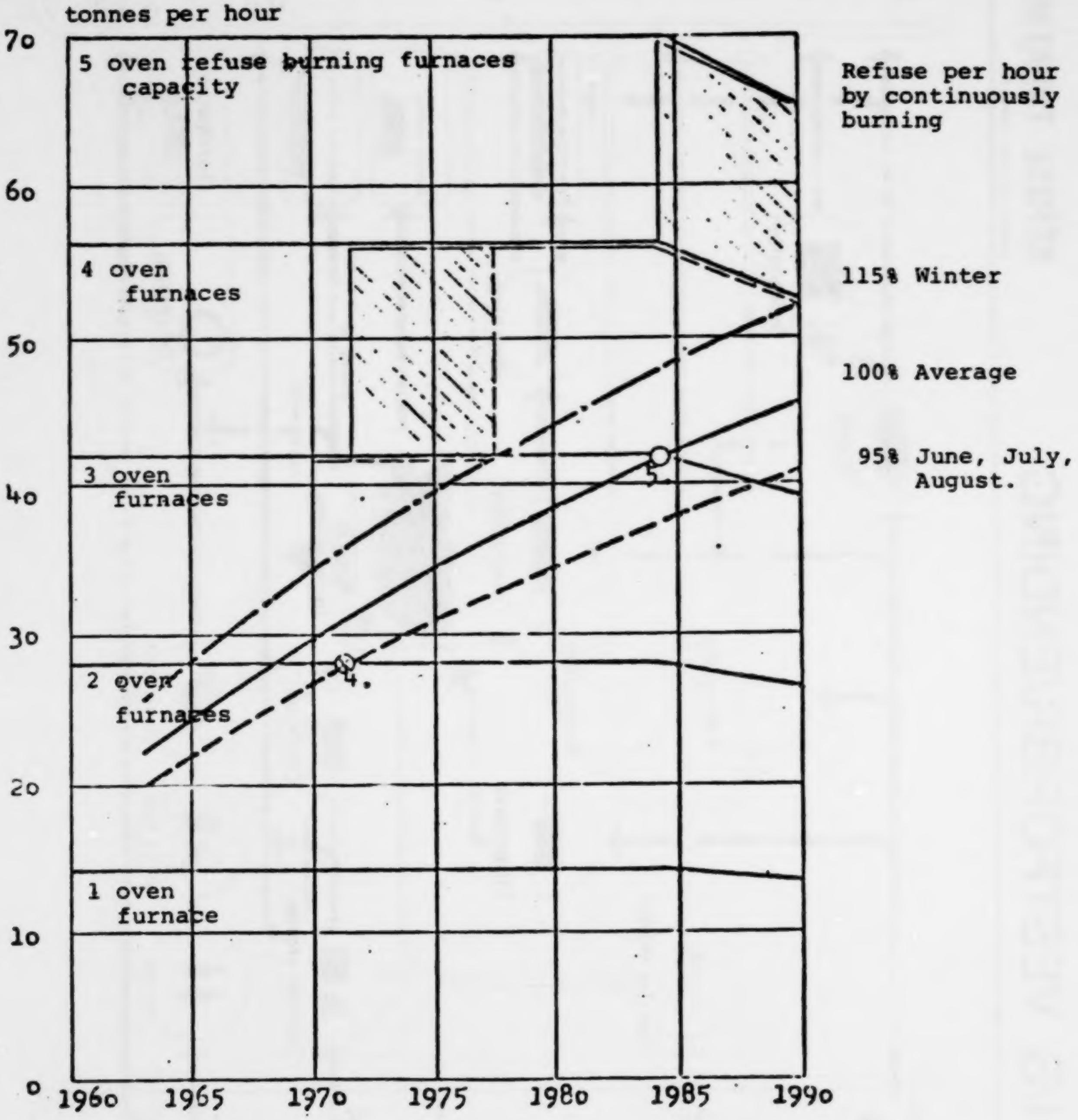
Table 15-3. INHABITANT AND QUANTITIES OF REFUSE FOR COMBUSTION

		1975	1980	1985
Inhabitants (people)	Copenhagen	250,000	250,000	250,000
	Suburbs	340,000	375,000	390,000
	Total excl. G+L-T	590,000	625,000	640,000
	Gentofte and Lyngby-Taarbæk	155,000	157,000	150,000
	Total incl. G+L-T	745,000	782,000	800,000
Household refuse (tonnes/year)	Copenhagen	92,000	100,000	108,000
	Suburbs	78,000	95,000	117,000
	Total excl. G+L-T	170,000	195,000	215,000
	Gentofte and Lyngby-Taarbæk	55,000	60,000	65,000
	Total incl. G+L-T	225,000	255,000	280,000
Industrial and garden refuse (tonnes/year)	Copenhagen	23,000	25,000	27,000
	Suburbs	22,000	25,000	28,000
	Total excl. G+L-T	45,000	50,000	55,000
	Gentofte and Lyngby-Taarbaek	25,000	25,000	25,000
	Total incl. G+L-T	70,000	75,000	80,000
Total quantities of refuse for combustion (tonnes/year)	Copenhagen	115,000	125,000	135,000
	Suburbs	100,000	120,000	135,000
	Total excl. G+L-T	215,000	245,000	270,000
	Gentofte and Lyngby-Taarbæk	80,000	85,000	90,000
	Total incl. G+L-T	295,000	330,000	360,000

Gentofte and Lyngby-Taarbaek are big enough cities, far enough removed to not be considered suburbs in this tabulation.

One furnace free for inspection in the summer.

Includes Copenhagen, suburbs; Gentofte, Lynby and Taarbaek.



● Plant expansion for fourth furnace in 1972.

O Plant expansion for fifth furnace in 1985.

FIGURE 15-9. LONG-RANGE PLANNING OF FURNACE ADDITIONS

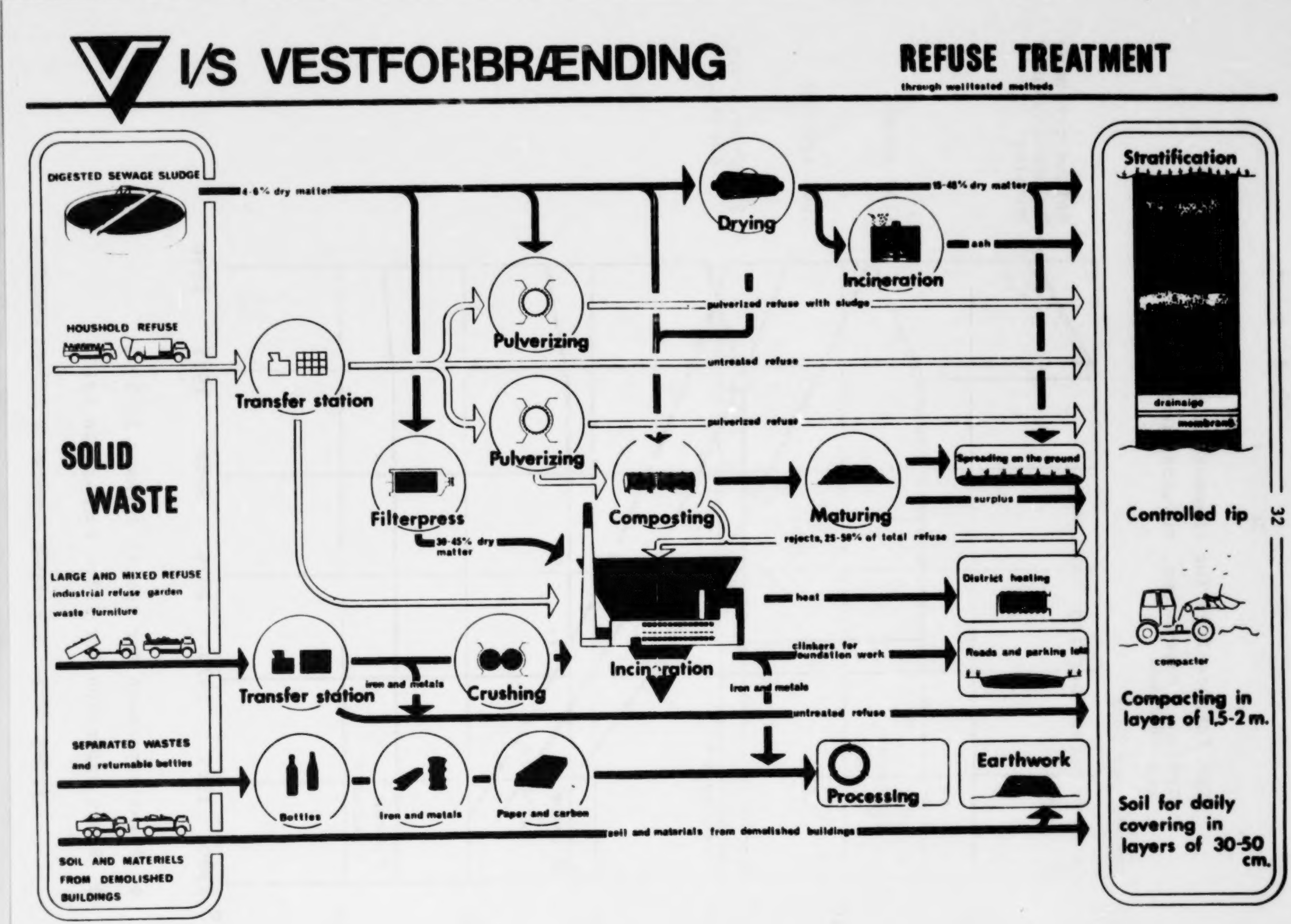

I/S VESTFORBRÆNDING
REFUSE TREATMENT
through welltested methods
DIGESTED SEWAGE SLUDGE
4-6% dry matter
HOUSHOLD REFUSE
SOLID WASTE
LARGE AND MIXED REFUSE industrial refuse garden waste furniture
SEPARATED WASTES and returnable bottles
SOIL AND MATERIELS FROM DEMOLISHED BUILDINGS
Transfer station
Pulverizing
Pulverizing
Filterpress
30-45% dry matter
Drying
15-45% dry matter
Incineration
ash
pulverized refuse with sludge
untreated refuse
pulverized refuse
Composting
Maturing
Spreading on the ground
surplus
rejects, 25-50% of total refuse
Incineration
heat
District heating
clinkers for foundation work
Roads and parking lots
iron and metals
Transfer station
iron and metals
Crushing
untreated refuse
Bottles
Iron and metals
Paper and carbon
Processing
Earthwork
soil and materials from demolished buildings
Stratification
drainaige
membrane
Controlled tip
32
compactor
Compacting in layers of 1,5-2 m.
Soil for daily covering in layers of 30-50 cm.

FIGURE 15-10. TOTAL ENVIRONMENTAL AND SOME ENERGY PROGRAM AT COPENHAGEN: WEST

Philosophy of Cooperation

It would not be possible for each muncipality to carry out such examinations and, furthermore, it would not be possible economically for each municipality to meet with the future environmental demands made to the refuse treatment in Denmark.

VOLUND'S RELATION TO THE NORTH AMERICAN MARKET

Volund A/G initiated activity in North America, January 9, 1948 with the F. L. Smidth & Co. Smidth had the "sole and exclusive rights to make, sell and/or use the VOLUND INCINERATOR SYSTEM ... in the United States ... Canada and Mexico".

Also in 1948, Smidth and the Hardaway Construction Company of Columbus, Georgia formed a joint venture company called International Incinerators Incorporated (III) with offices in Atlanta, Georgia. III was to "devote its best efforts to an aggresive attempt to obtain orders from purchasers... (in North America) ... for the sale or installation of apparatus and equipment made in accordance with the VOLUND INCINERATOR SYSTEM".

With this charter, III sold 13 municipal waste incinerators, 2 of which had energy recovery. They also sold 3 industrial waste incinerators. During this time of cooperation, III utilized many of the Volund A/G patents and site-specific drawings. In addition, III developed many of their own techniques and filed patents. Eventually many of the early Volund A/G patents expired. Yet Volund A/G continued to file patents in America.

With the Congress passing the Clean Air Act of 1970 and the ensuing regulations on incinerators, many units closed. Few new orders (regardless of manufacturer) were placed after 1970. In fact III had some of the very last orders. Nevertheless the future looked bleak.III survived on their replacement parts business.

Eventually the license agreement between F. L. Smith (the 50 percent owner of III) ceased effective December 31, 1975. Smidth then sold its shares to the other original joint partner, The Hardaway Construction Company.

Subsequently, Volund A/G and III (now 100 percent owned by Hardaway) were not able to come to agreement on a new license.

Volund A/G initiated efforts to find a new licensee. Finally a joint venture corporation was founded and is known a Volund USA.

An abreviated name used orally is VUSA. It is owned jointly by the following parties:

Volund A/G (Glostrup, Denmark)	30 percent
Waste Management, Inc. (Oak Brook, Illinois)	30 percent
Jack Lyon & Assoc. (Washington, D.C.)	30 percent
Others	10 percent

We have been informed that VUSA would like potential purchases of VOLUND INCINERATOR SYSTEMS to contact:

Sales, Construction, Operations

Mr. Ronald Heveran
Director of Marketing
Advanced Systems Group
Waste Management, Inc.
900 Jorie Boulevard
Oak Brook, Illinois 60521

Engineering, Design, Purchasing and Start-Up

Mr. Gunnar Kjaer
President
Volund USA
900 Jorie Boulevard
Oak Brook, Illinois 60521

Frankly, both Volund A/G and III lay claim and probably desire recognition for these American plants. All 13 municipal refuse plants are shown in the current inventory published separately by both Volund A/G and III.

Effectively, this means that a community desiring "something that looks like a Volund grate followed by a rotary kiln" has two potential vendors. Some would speculate that this is an unnatural situation that still has not settled.

VOLUND'S PREFERRED PROCEDURE FOR SYSTEM STARTUP

Volund has prepared a block flow diagram showing how they view the developmental process for these systems (see Figure 15-11).

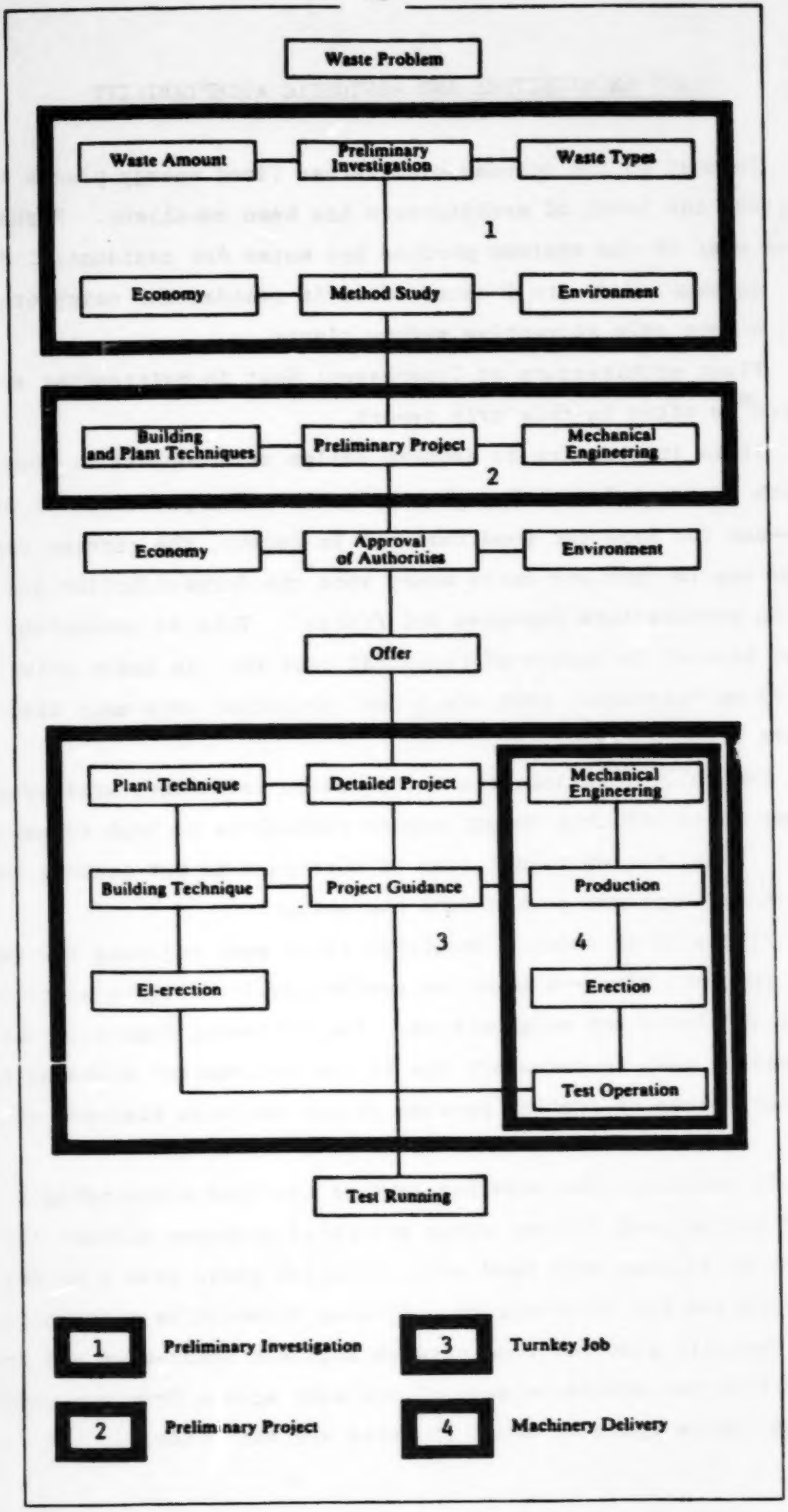

Waste Problem
Waste Amount
Preliminary Investigation
Waste Types
1
Economy
Method Study
Environment
Building and Plant Techniques
Preliminary Project
Mechanical Engineering
2
Economy
Approval of Authorities
Environment
Offer
Plant Technique
Detailed Project
Mechanical Engineering
Building Technique
Project Guidance
Production
3
4
El-erection
Erection
Test Operation
Test Running
1 Preliminary Investigation
3 Turnkey Job
2 Preliminary Project
4 Machinery Delivery

FIGURE 15-11. VOLUND'S PROCEDURE FOR SYSTEM DEVELOPMENT

PLANT ARCHITECTURE AND AESTHETIC ACCEPTABILITY

In most of the Scandanavian refuse fired energy plants that were visited, the level of architecture has been excellent. Perhaps this is because most of the systems produce hot water for residential district heating. As such, they are located often in residential neighborhoods that will accept only attractive refuse plants.

Plant architecture at Copenhagen: West is outstanding and will be referred to often in this trip report.

It is interesting to compare design philosophies at Copenhagen (West) with those at Zurich Hagenholz #3 unit. The philosophies are opposite--and for apparent good reason. In Zurich, the current design philosophy was to "put any extra money into the furnace/boiler and to 'get by' on architecture features and frills". This is consistent with the recent history in Zurich of technical problems (in units prior to the Unit #3 at Hagenholz) that are a real potential with many high temperature steam systems.

Generally speaking, the Scandanavian refractory wall systems produce hot water and thus do not expose themselves to high temperature corrosion. Thus, the emotional fear of corrosion is not present and excessive monies are not poured into the boiler.

Figure 15-12 shows a beautiful white swan enjoying the reservoir at the West plant--a plant so aesthetically designed as to be acceptable in almost any neighborhood. The following Figure 15- 13 shows the landscaping plan so necessary due to the residential surroundings and the high volume of traffic passing on the two main highways of the area.

In addition, the existing land at the time surrounding a pond could not be used for any other practical purposes without the involvement of filling with hard material which could give a proper stable foundation for construction. Filling in would be quite expensive.

The city plan for road network included motor-ways and freeways. The site was chosen because of its easy access from two major highways. Thus, ample space of about 25 acres was set aside.

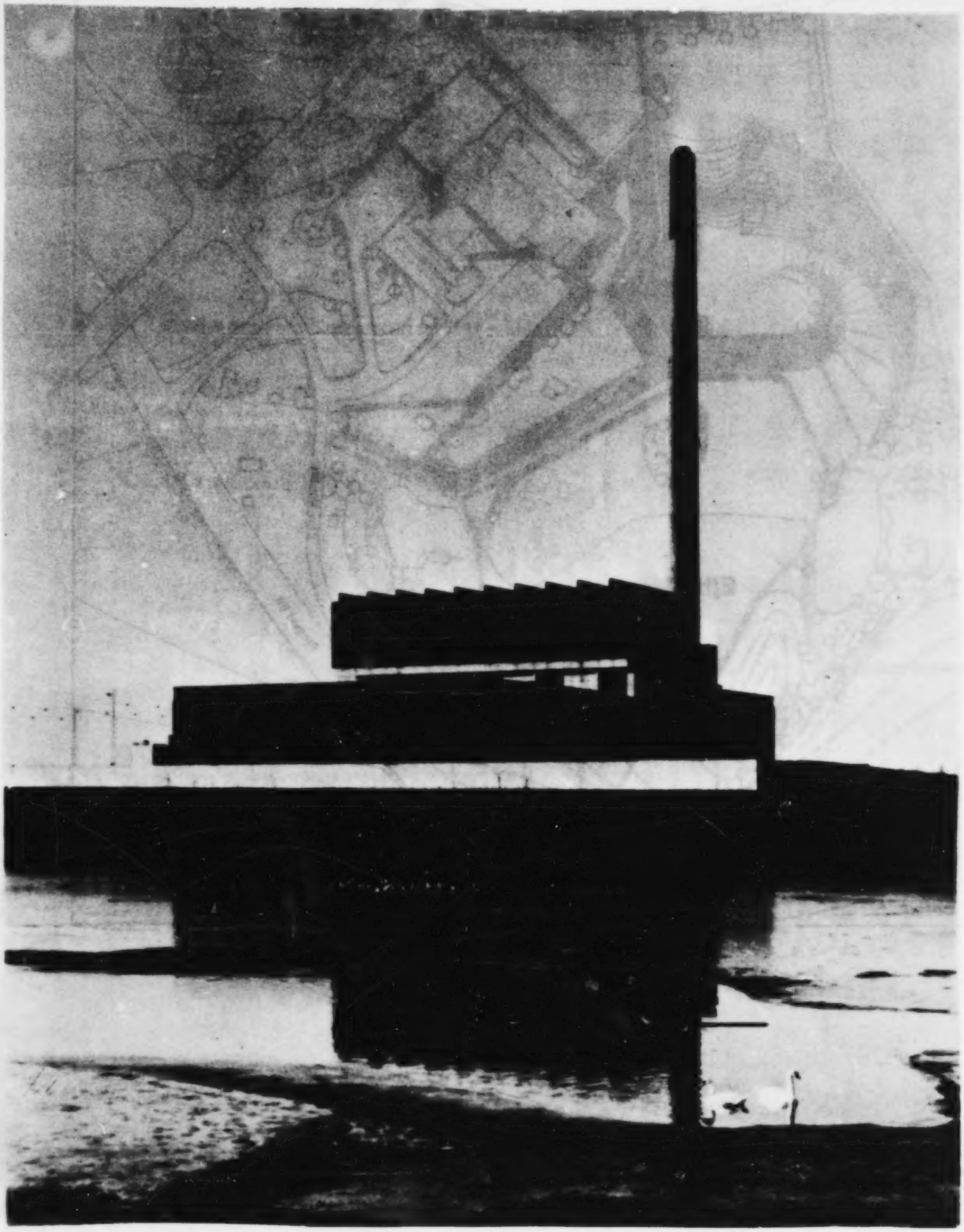


FIGURE 15-12. SWANS IN POND ON PROPERTY OF COPENHAGEN WEST

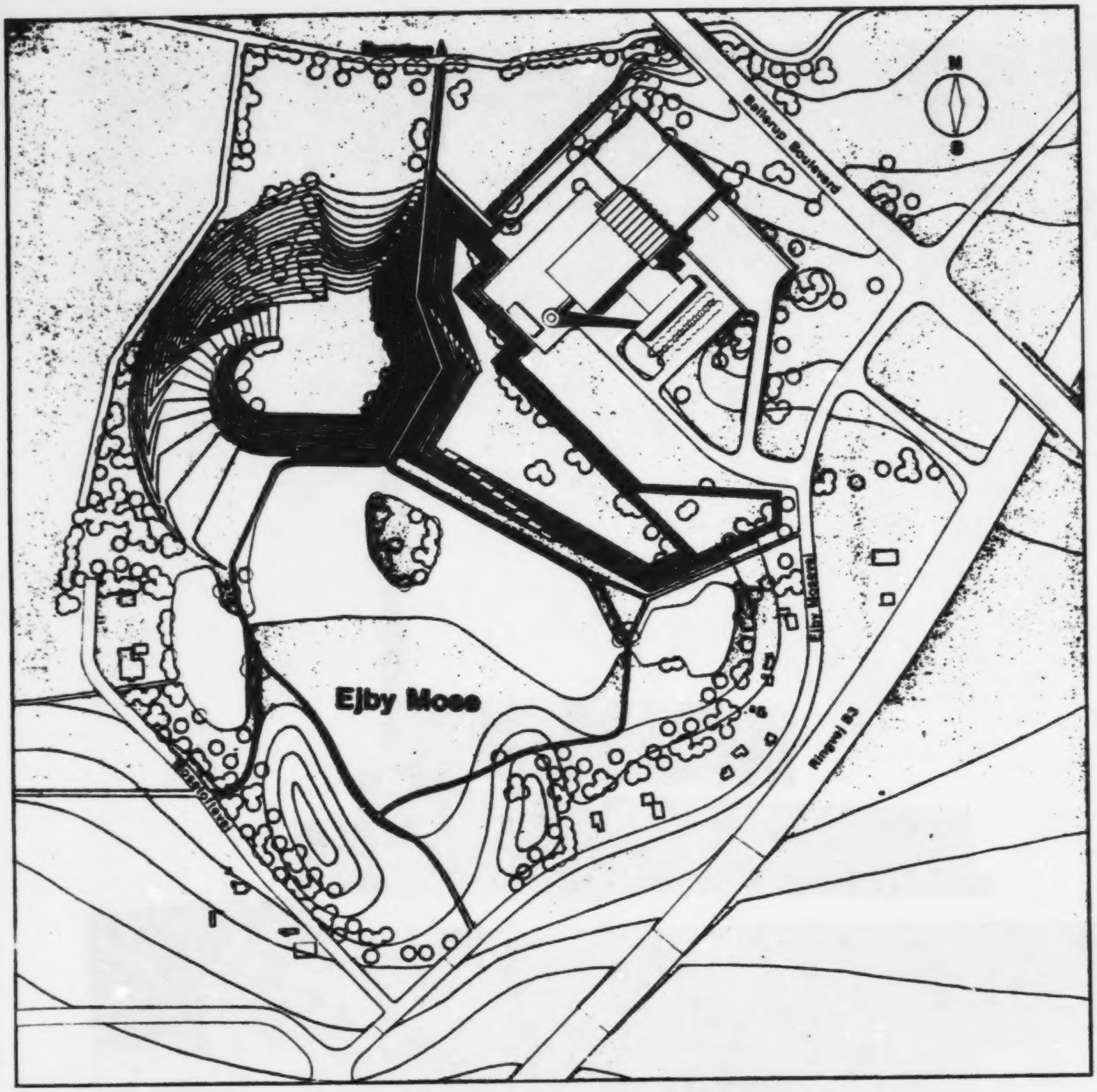

N
S
Ballerup Boulevard
Ejby Mosevej
Ringvej B3
Ejby Mose

FIGURE 15-13. ARCHITECTS OVERHEAD PLAN FOR LANDSCAPING AT COPENHAGEN: WEST RFSG

The aerial photo in Figure 15-14 shows the intensity of land use ajoining the plant property. Finally, the exterior wall theme is portrayed in the architect's rendering in Figure 15-15.

Another important comparison is the contracting agreement at West versus the agreement at Amager. West was constructed under a "cost plus percentage fee" contract. Amager, however, was constructed under a "fixed price" contract. Despite the identical refuse input requirements and similar processing equipment, there was more attention to aesthetics at the West plant. As such, West was 25,000,000 DKr more expensive.

For buildings both plants were constructed on the same basis while for machinery there was a price escalation.

The building height is 50 m (164 feet). The machinery hall is 35 m (115 feet) high. However, the stack is very tall at 150 m (492 feet).

Unlike many plants, everything that could produce noise is enclosed. Referring to Figure 15-16, notice that the tipping floor for refuse collection trucks and for transfer trailers is fully enclosed. The electrostatic precipitator, often on plant roofs is enclosed. Also, all of the ash handling activities are located in the lower parts of the plant.

Perhaps the only deviation from the "full enclosure--no noise" philosophy is the ash reclamation activity. Ash reclamation, as explained later, was only started in 1976, long after the plant was otherwise finished. The strong presence of the architect apparently disappeared. While not enclosed, the processing is tastefully layed out.

The West administration building would be the envy of many American corporations as a headquarters structure. The conference or board room is so expansive that it is informally divided into three sections (a) board room table, (b) small conference table and (c) lounge. A part of the room is shown in Figure 15-17. Not many incinerator control rooms have a plush lounge area like the one shown in Figure 15-18. Comments were made several times during Battelle's visits in Scandanavia that such pleasant surroundings are necessary to attract and keep the desired kind of employees.

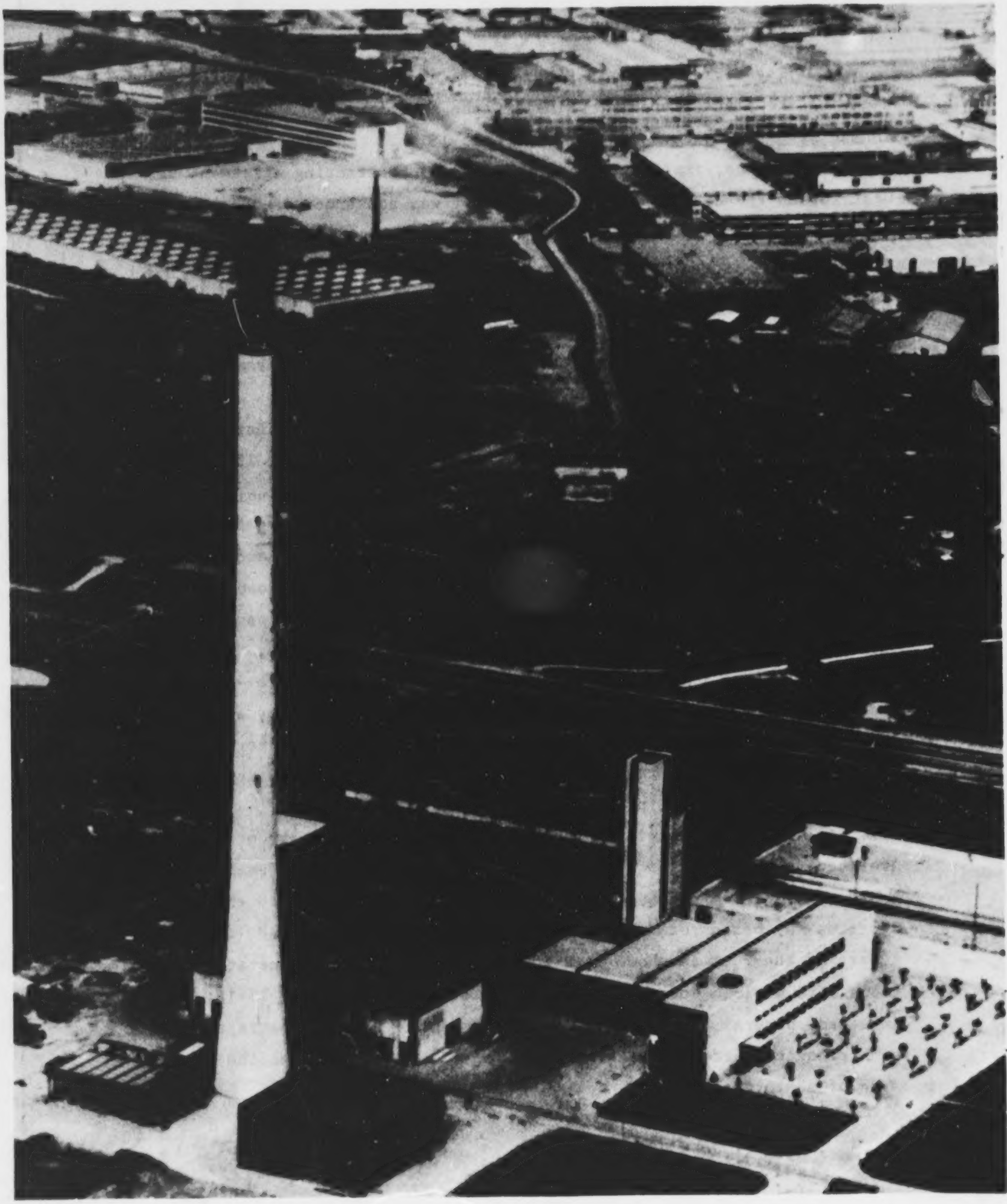


FIGURE 15-14. AERIAL PHOTOGRAPH OF COPENHAGEN: WEST AND ITS SURROUNDINGS

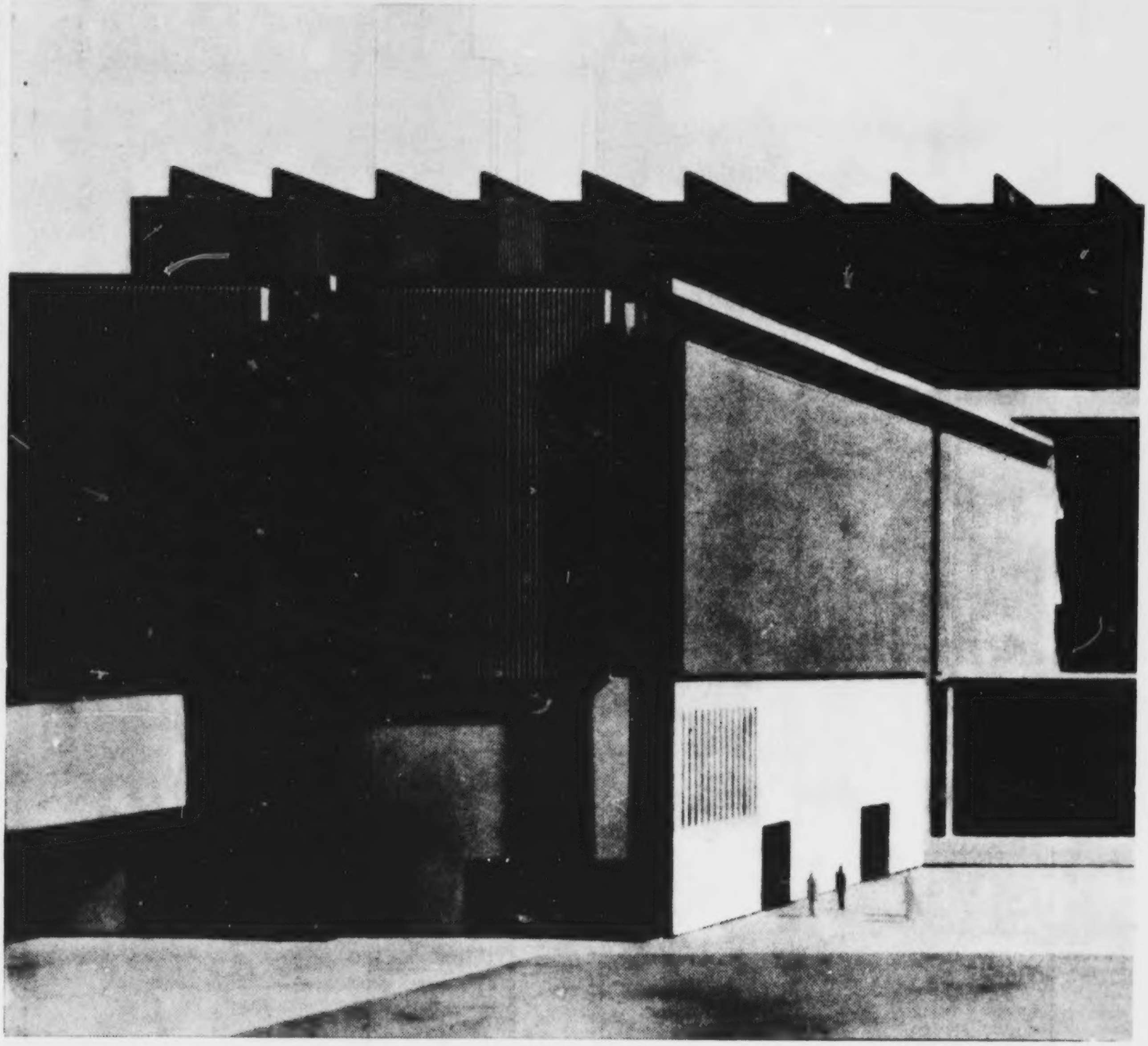


FIGURE 15-15. EXTERIOR WALL ARCHITECTURE THEME AT COPENHAGEN: WEST

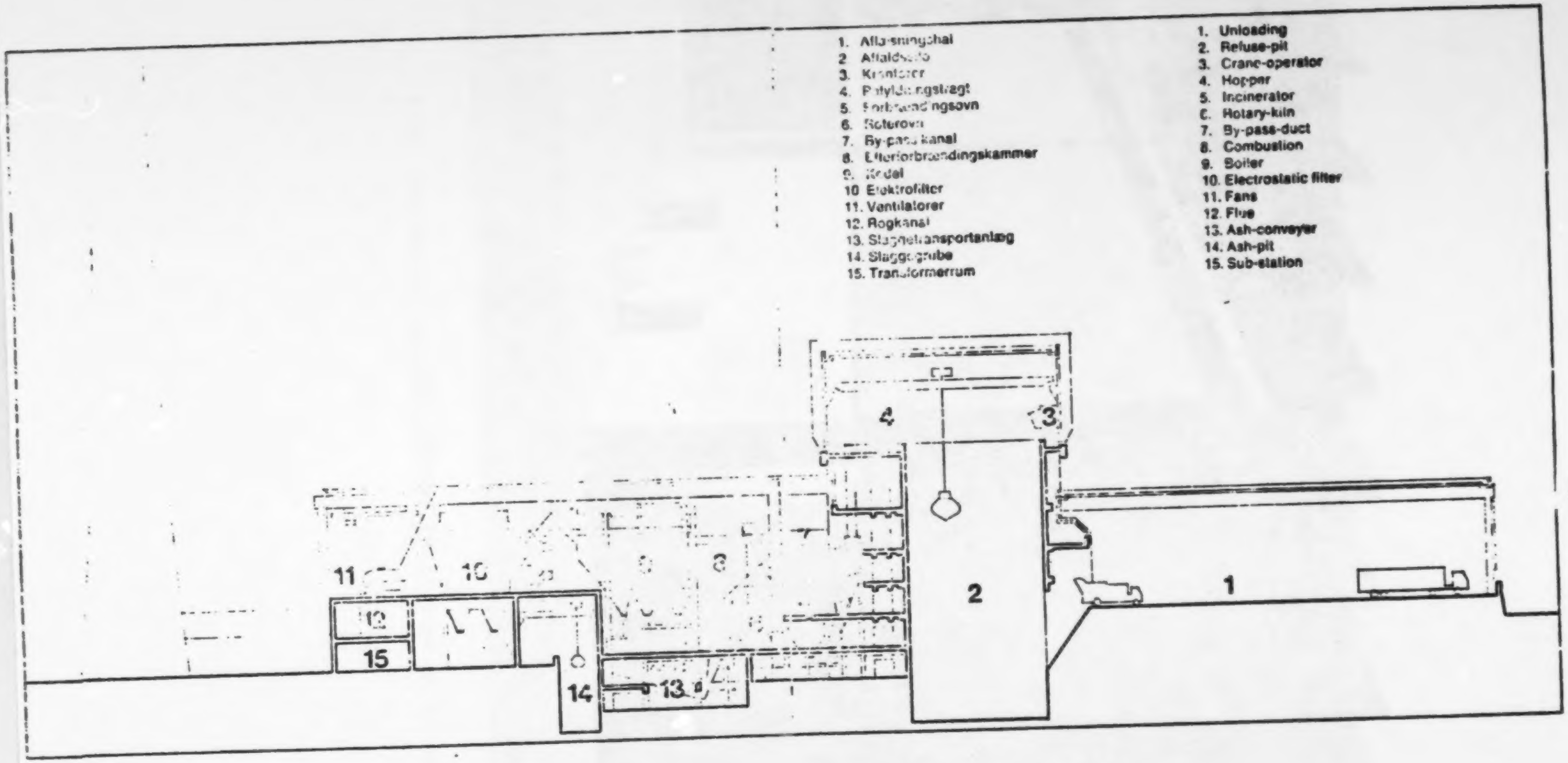

1. Aflæsningshal
2 Affaldssilo
3. Kranfører
4. Påfyldningstragt
5. Forbrændingsovn
6. Roterovn
7. By-pass kanal
8. Efterforbrændingskammer
9. Kedel
10 Elektrofilter
11. Ventilatorer
12. Røgkanal
13. Slaggetransportanlæg
14. Slaggegrube
15. Transformerrum
1. Unloading
2. Refuse-pit
3. Crane-operator
4. Hopper
5. Incinerator
6. Rotary-kiln
7. By-pass-duct
8. Combustion
9. Boiler
10. Electrostatic filter
11. Fans
12. Flue
13. Ash-conveyer
14. Ash-pit
15. Sub-station
1
2
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FIGURE 15-16. CROSS-SECTIONAL SCHEMATIC OF COPENHAGEN: WEST RFSG

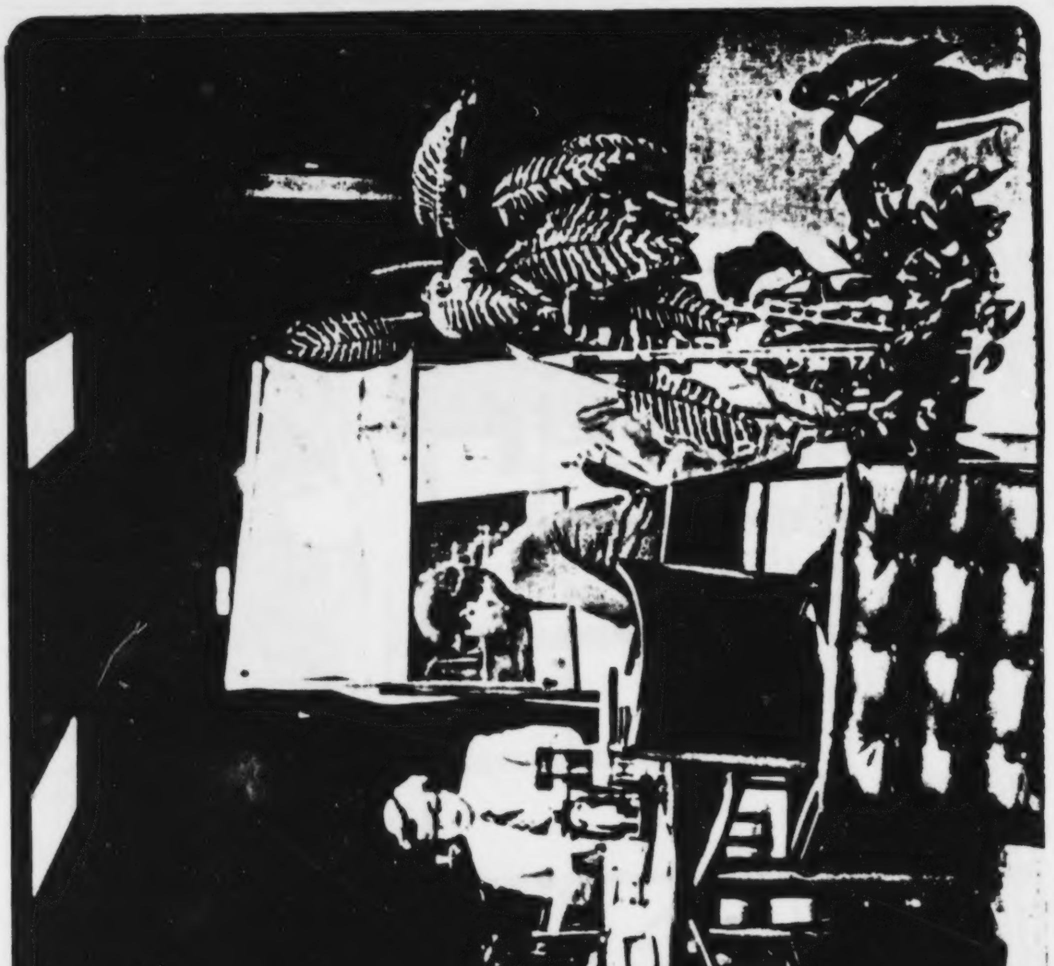

FIGURE 15-17. SPACIOUS CONFERENCE ROOM AT COPENHAGEN: WEST

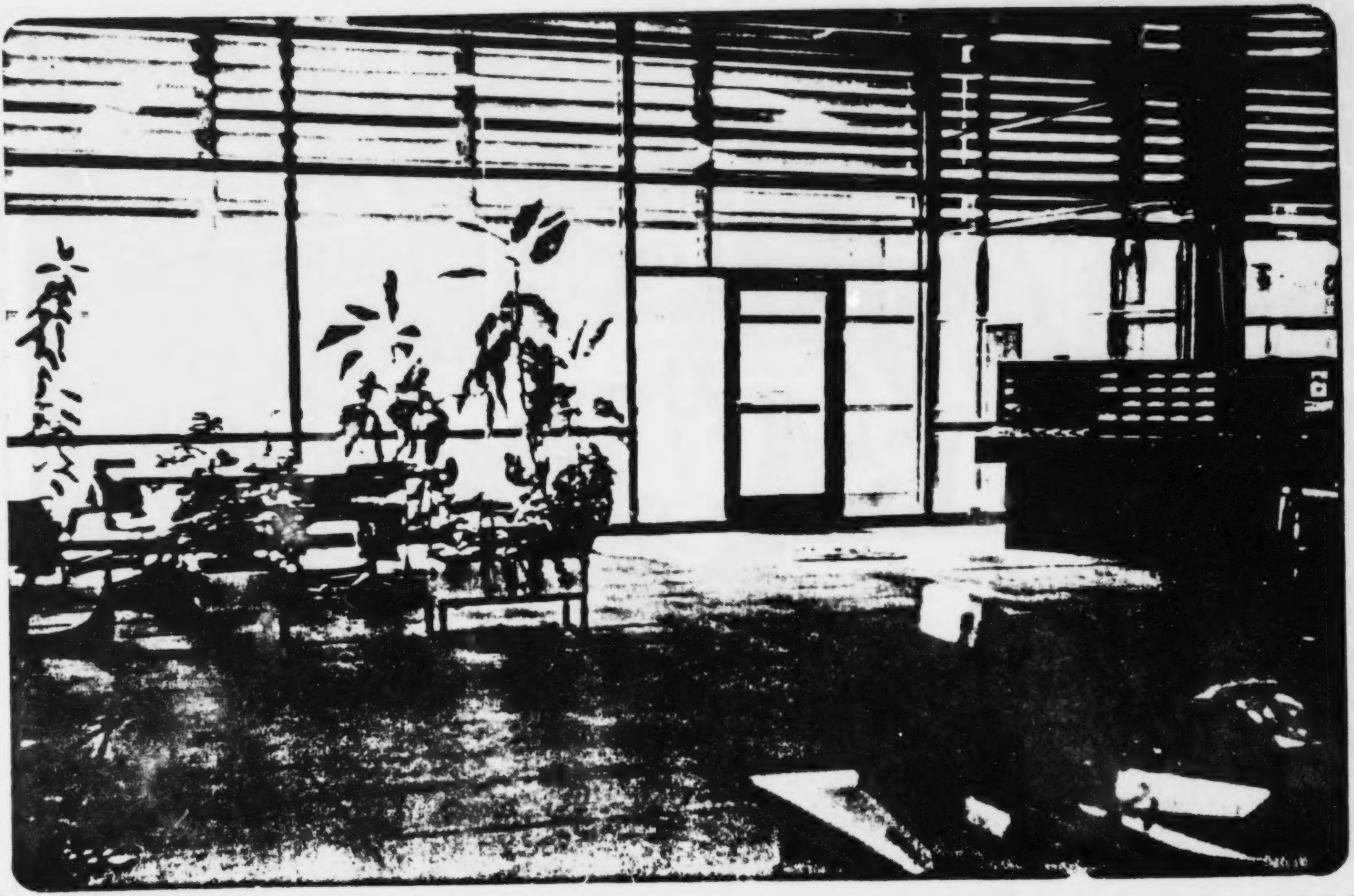

FIGURE 15-18. COMFORTABLE AND PLEASANT LOUNGE AREA CONTROL ROOM AT COPENHAGEN: WEST

TOTAL OPERATING SYSTEM

Battelle's host for the Volund visit was Gabriel S. Pinto. In 1976, he wrote an excellent article in an internal Volund publication* that discusses basic design of the total operating system. The following summarizes the article.

For purposes of the vendor's guarantee to the customer, there must be a clear understanding of the relation between Maximum Rated Capacity (MRC) and the Lower Heating Value (LHV). The numbers used in the example figure are those associated with the Volund grate furnaces followed by the rotary kiln furnaces.

For each furnace designed by Volund, a theoretical diagram, similar to Figure 15-19, is developed. Its purpose is to show how the MRC (tonnes/hr) is a function of net calorific value (kcal/kg).

As an example, assume that the LHV is 2,000 kcal/kg. Typically, such MRC waste has the following composition:

Inerts		25%
Moisture		30%
Combustibles		
Carbon	8.6%	
Cellulose	34.8%	
Plastics	1.6%	
Total Combustibles		45%
		100%

The refuse feeder is to be adjusted so that the refuse layer on the grate is 1 m (3.3 ft). This type of refuse, at the named layer thickness, has an average density of 200 kg/m^3 (337 pounds/yd^3).

More must be known about the specific system before the MRC answer (in tonnes/hour) can be given. The effective grate area must be known. The following formula relates key variables:

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* Pinto, Gabriel S., "Maximum Rated Capacity (MRC) on Volund Rotary Kiln Furnaces".

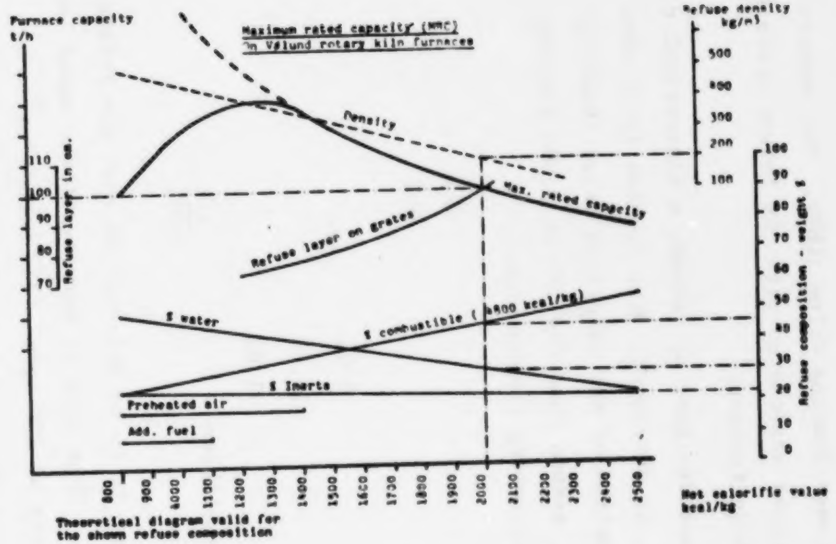


FIGURE 15-19. MAXIMUM RATED CAPACITY ON VOLUND ROTARY KILN FURNACES

$$\text{MRC } \left(\frac{\text{tonnes}}{\text{hour}}\right) = \frac{\text{Effective Grate Area } (m^2) \cdot \text{Grate Load } \left(\frac{\text{kcal}}{m^2 \cdot \text{hour}}\right)}{\text{Net Calorific Value } \left(\frac{\text{kcal}}{\text{kg}}\right) \cdot 1000 \left(\frac{\text{kg}}{\text{tonne}}\right)}$$

At this point, some rules of thumb need to be applied.

- For hotter refuse with LHV of 1800 to 2500 kcal/kg, the grate load ranges from 600,000 to 650,000 kcal/m^2 · hour
- For cooler refuse with LHV under 1800 kcal/kg, the grate load ranges from 450,000 to 550,000 kcal/m^2 · hour

Experience of Volund must be used to actually estimate the grate load. But once estimated, the capacity can be determined. Mr. Pinto's example does not refer to any one system so we have arbitrarily added capacity figures of 5.5 to 8.5 tonnes per hour.

An important design consideration can be seen from the capacity versus LHV curve. It is uni-modal peaking at 1200 - 1400 kcal/kg. As an example, it is assumed that the plant is nominally designed to burn 7.0 tonnes per hour of refuse assuming it to have a 2000 LHV.

Perhaps on a Spring day, rain is excessive. The moisture percent rises from its normal 30% to 37%; the combustibles fall from 45% to 38%; the density increases from 200 kg/m^3 to 300 kg/m^3 and the inerts remain constant. The air preheater remains unchanged and the use of any other fuel remains unchanged.

With the conditions of the wet waste given, the operator may increase the feed rate, raise the feed layer thickness to 120 cm (4 ft) and thus increase the throughput from its nominal 7 tonnes per hour up to 8 tonnes per hour.

This of course has a logical limit. If the refuse becomes too wet, full of inerts, and lacking in LHV, then less tonnes per hour can be processed. The furnace could easily choke on even 5 tonnes per hour of soggy rags and house furnace ashes if autothermic reactions are not possible.

In the other direction, above a LHV of 2000, this particular furnace should process slightly less refuse per hour.

Mr. E. Blach, Volund's former chief engineer, wrote in 1969 an excellent paper outlining Volund's product offerings and its philosophy. The following section presents some of the philosophy of how plants should be operated. Several of his other sections appear later.

Forms of Operation

The best way of running an incinerator plant is running it 24 hours a day, i.e. continuous operation. The big variations of temperature at start and shut-down cause more wear in a furnace and the auxiliary machinery than a steady operation, and corrosion and cleaning problems, etc. in the boiler part also decrease by contiqual operation. With regard to possibilities of maintenance and repair, continual operation is not possible for a 1-furnace plant, and that is one of the reasons why an incinerator plant should usually consist of at least 2 furnace units. Unfortunately, this is often not economically possible at the small plants.

An ideal way of operation for plants with several furnaces is obtained by always keeping a spare oven, while the other or the others run continuously. Through a convenient rotation so that the furnaces alternately are taken out of operation there is plenty of time for inspection, maintenance and repair of each furnace. Small damages can thus be found and repaired before they spread and require big and expensive repairs. At one-furnace plants, the possibilities of inspection are smaller and it can be tempting to let a long time pass between maintenance and repair stops so that the damages grow big and expensive to repair.

With non-continuous operation, which in practice is 1 or 2 shifts operation, the furnace is stopped, when the operation is discontinued, e.g. the furnace is fed with suitable amount of refuse proportionally to the stand-still period, after which the grate movement and combustion air as well as I.D. fan are stopped. The natural draught will then keep a slow combustion, which develop sufficient heat to keep the plant warm all through so that it can quickly get up to full capacity, when it is started again. After a couple of hours the temperature of the flue gases will be so low, however, that there is the risk of condensation, and thus corrosion in the convection part of the boiler, although the boiler water still can be kept at full temperature, and the boiler shunt can ensure min. 70° C return flow temperature. Therefore, at stops of more than 6-8 hours there must be taken special measures, such as by-pass with damper around the boiler and its convection part. This is a rather difficult construction to carry out in sufficiently strong and practical form because of the high temperatures.

Furthermore, it results in the operational inconvenience that changing over cannot take place till the flue gas temperature is below 400° C, which normally means after 3-4 hours' stop.

During week-end stoppages the temperature of the boiler water cannot be maintained, and it will in this case be necessary also to keep the boiler warm by circulation of hot water.

Note: Three configurations of grate and kiln are possible. The rotary kiln alone is used only on special industrial wastes and at low capacities. For municipal waste, when the kiln is used it is always preceded by the Volund. For smaller communities, a grate alone (with no rotary kiln) is sufficient for municipal waste.

REFUSE FIRED HOT WATER GENERATOR EQUIPMENT

Waste Input

The plant receives normal household, commercial, and light industrial refuse. Because of its two shredders it can also accept substantial quantities of bulky waste. Grass clippings and vegetation are perhaps more prevalent than in many other systems in the Spring and Autumn. There is talk now of accepting sewage sludge in the future.

Public and private organizations collect and deliver the waste in normal garbage collection trucks. Transfer truck-trailers from Hillerod bring waste from the northern communities. Special source separation trucks bring refuse into the special bin area (Figure 15-20) at the elevated entrance (Area 2) to the plant as shown in Figure 15-21. Private citizens and businesses also use these bins.

Weighing Operation

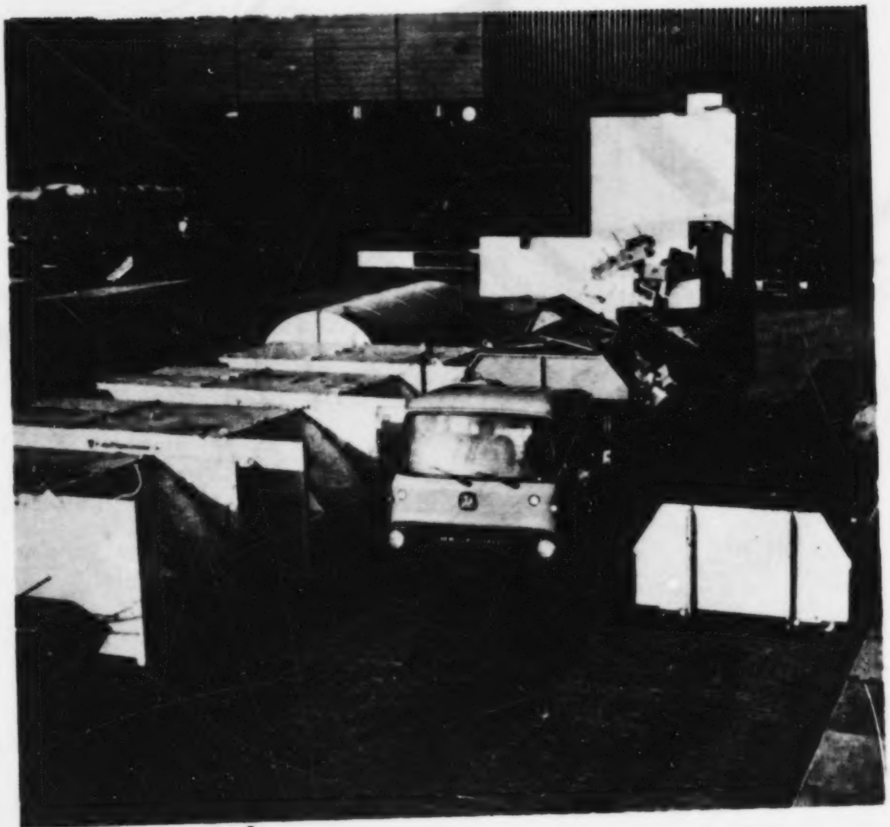
Arriving trucks (some may visit the bins prior to weighing to discharge source separated items) proceed to one of the two load cell, 50 tonne (55 ton) scales manufactured by Philips of Holland (see Figure 15-22). Drivers produce their universal plastic cards that identify the vehicle owner, etc. This information, along with the gross weight, is fed into the computer, where the tare weight, mailing address, etc. are stored.

Relevant information is displayed (see Figure 15-23) in the attractively styled scale control room on the cathode ray tube monitor. Additional monitors inform the scale operator of traffic patterns within the tipping door. The scale operation can also respond to requests communicated from the crane operator as to where waste should go to better even the calorific content.

Occasionally the plastic cards jam, break, or become lost. In this event, the driver would have to get out of the truck and spend several minutes in the scale house filling out a form. The cards were replaced on an as needed basis. They have changed the system so that every six

Plastic Card Reader

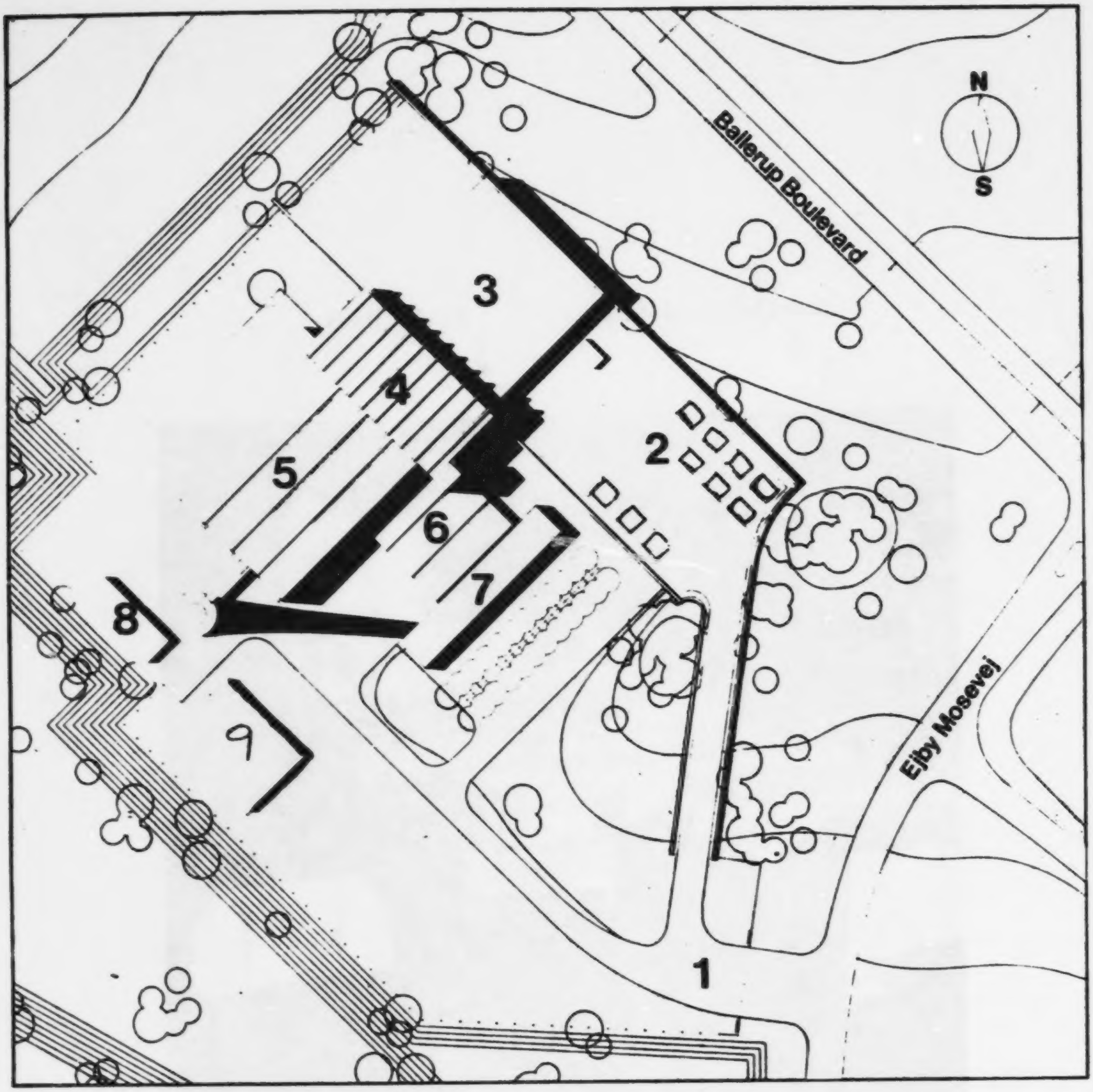
Scale House



Recycling Station

Paving Cinder Blocks Made From Recovered Ash

FIGURE 15-20. SOURCE SEPARATION RECYCLING STATION AT COPENHAGEN: WEST


N
S
Ballerup Boulevard
Ejby Mosevej
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9

1. Entrance
2. Recycling Bin Area and Scale
3. Enclosed Tipping Area
4. Refuse Pit
5. Furnace/Boiler/Pollution Control Room
6. Maintenance Area
7. Administration Building
8. Air Cooled Steam Condensers
9. Permanent Standby Boiler

FIGURE 15-21. MODULAR UNIT LAYOUT AT COPENHAGEN: WEST

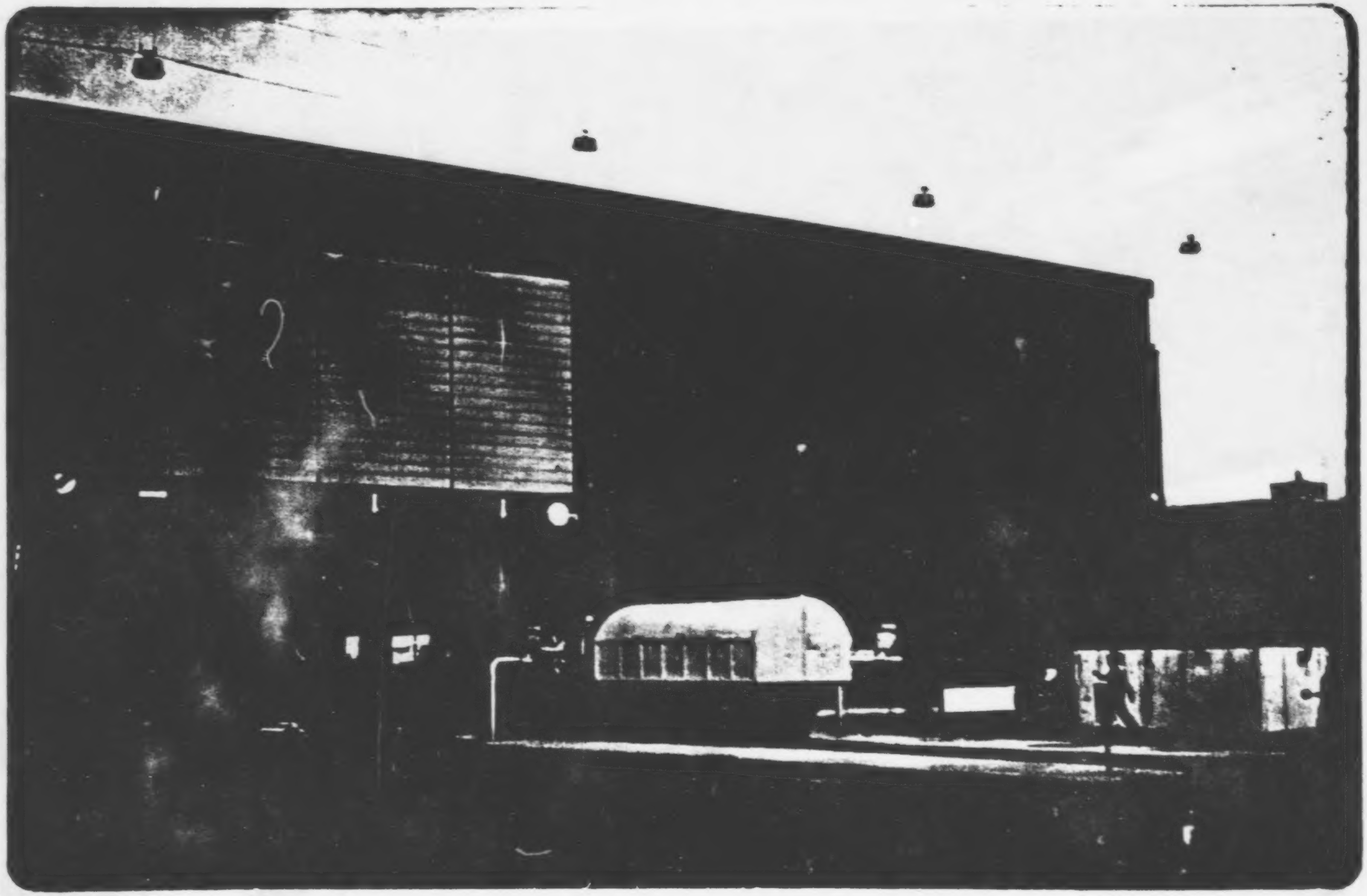


FIGURE 15-22. TRUCK DRIVER INSERTING PLASTIC CARD TO ACTIVATE SCALE, COMPUTER CALCULATION, TELEVISION DISPLAY AND PERMANENT RECORD AT COPENHAGEN: WEST

FIGURE 15-23. SCALE HOUSE CONTROL PANEL WITH TELEVISION MONITORS OF TIPPING FLOOR AND COMPUTER PRINTOUT OF WEIGHING INFORMATION AT COPENHAGEN: WEST

months all of the plastic cards are changed at once.

At the time of the visit in October 1977, a particular card would work at Amager, West, and the Hillerod transfer station. An identical Philips system was under consideration for the Roskilde Volund plant as well. In theory the system could be used throughout Denmark to the advantage of all.

Provisions to Handle Bulky Wastes

The scale operator directs drivers with bulky wastes to either of the two Lindeman "Lomal 10" shears. The second shear was added in 1975. Now, about 40-50% of the refuse input is processed through the shears. Previously, bicycles, tubs, furniture, etc. had been jamming in the refuse hopper, chute, and ash discharge operations. The current rule to drivers is that all garbage collection trucks and transfer truck-trailers disgorge directly into the refuse pit. Equally as firm is the rule that all other trucks (especially detachable container loads) must discharge to the Lindeman shears.

The shears are adjacent to the pits. They are rated at 80 m^3/hr. Operation is intermittent and only on the day shift when the operator is present. The drive is hydraulic.

The maintenance record has been excellent. Blades are replaced usually after one or two years. With the rule that all miscellaneous truck loads must go to the shear, several problems have arisen.

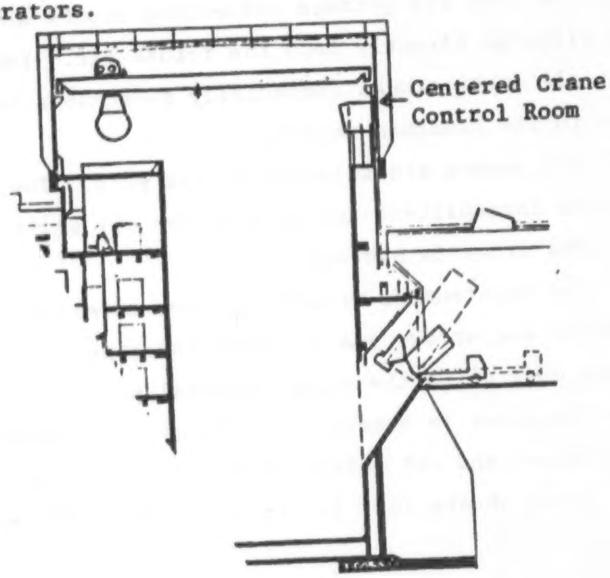
The shear is sometimes difficult to operate when overloaded with small-sized and wet refuse such as a truck load of grass clippings.

These shears cost 2.5 to 3.5 million DKr each.

Waste Storage and Retrieval

West has a pit 56 m (184 feet) long, 17 m (56 feet) wide, and 13.5 m (44 feet) deep. The capacity to the tipping floor door level is 12,500 m^3 (16,350 yd^3). However, with refuse piled against several doors and by piling refuse against the wall to the furnace, the maximum capacity can be doubled to 25,000 m^3 (32,700 yd^3). This converts to four days maximum storage. The specific weight or density is 0.2 to 0.3 tonnes/m^3 (337 to 506 pounds/yd^3).

The 12 refuse doors are described as double hinged flap doors 8.0 m (26.3 feet) high, 3.8 m (12.5 feet) wide, and 122 mm (5 inches) thick. They are operated hydraulically. The tipping configuration was designed carefully to allow for a door and also to permit full view of tipped refuse by the crane operators.



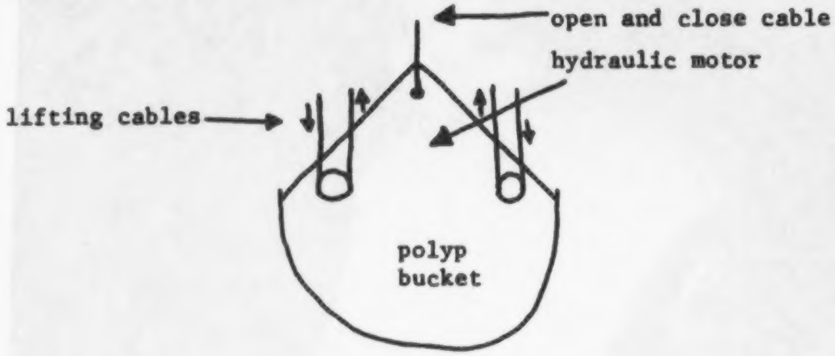
The West pit is much deeper by comparison than Amager. The West pit bottom is 4.0 m (13.2 feet) above sea level while Amager is 3.7 m (12.2 feet) below sea level.

There are no fire hoses at West. The local fire department is used for the pit fires.

The plant has two cranes (one active and one often in reserve), manufactured by Demag-Thomas Schmidt. Both crane operator chairs are located in the crane control room above the discharge doors and centered above doors 6 and 7, and at the hopper level. See Figure 15-24. Each crane is rated at 10.5 tonnes (11.5 tons). Television cameras aimed at the hopper assist the crane operator in setting the drop position over the hopper.

FIGURE 15-24. THE TWO CRANE OPERATORS IN THE CRANE CONTROL ROOM AT COPENHAGEN: WEST

Based on the many crane problems at Amager and the success in curing them, West was more properly designed and has had fewer problems. The polyp is controlled with a hydraulic motor located inside the bell of the polyp top. There is a sensor so that when the polyp is more than 45° from its level position, it switches off and refuses to permit further movement that might snag the cables. The polyp has additional stability due to the four lifting strands as compared to two strands in some less expensive systems as follows:



This cable and polyp system has worked exceptionally well and is considered well worth the extra money.

Furnace Hoppers, Feeders, and Swivel Gate

The hopper dimensions at its top opening are 6.5 m (20.1 feet) by 6.5 m (20.1 feet). Farther down, at its bottom, the dimensions are 2.3 m (7.6 feet) by 1.15 m (3.8 feet). Its height is 5.9 m (19.3 feet). The walls are made from 8 mm (.3 inches) plain carbon steel.

The filling chute has a slightly larger width dimension than the hopper: 2.35 m (7.7 feet) by 1.15 m (3.8 feet). It too is made of 8 mm (.3 inch) steel. The chute volume is 19 m^3 (671 ft^3).

The swivel gate or damper is located in the chute. It is opened when refuse falls on it and closed when no refuse is above it. Its function is to prevent burnback.

The damper's dimensions are 2.3 m (7.6 feet) by 1.26 m (4.2 feet) and is 10 mm (.4 inches) thick. The 2.3 m dimension gradually increases to 2.7 m (8.9 feet) near the furnace entrance.

Previously the damper (swivel gate) on Units 1, 2, and 3 was located 2 m (6 feet) below the hopper/chute interface. Severe burnback and metal warpage, as shown in Figure 15-25 was the result. The 12.7 mm (.5 inch) support iron plates warped in addition to the walls themselves. The plant successfully reduced serious burnback by raising the damper level to only .5 m (1.5 m) below the hopper/chute interface. West Units 1-3 are equipped with special pneumatic air hammers that can be used to dislodge jammed feed hoppers or chutes.

In planning Unit 4 (which began operation five years later), the designers also specified that refractory brick should be extended internally up to the hopper/chute interface. Even with this, there has been some burnback.

Another cause of burnback in the early years was that the crane operators would put too much refuse in. Except for flowing material, the hopper should always be empty. There should be no refuse above this kind of damper to interfere with its closing. Pursuasion and practice rectified this problem. Unless radioactive monitoring is used, the crane operator should view the hopper/chute interface if designed as West is designed.

Primary (Underfire) Air

The primary air intake is located on the hopper level as shown in Figure 15-27. As such, the hopper floor is very dusty as is the intake mesh screen also. In future designs, Volund will likely raise the mesh screen another 2 m (6 feet) above the hopper to reduce dust problems. The air is pulled in and down by the Nordisk 1490 rpm, which can pull 45,000 Nm^3/hour. The temperature is assumed to be 30° C (86 F) and the static pressure is 230 mm water (2.25 k pascals) (9.06 inches water).

Primary air is delivered to both the grate furnace and the rotary kiln, as described in greater detail in the Amager report.

Primary air is delivered to one of four hoppers under the grates: Grate I (1 hopper), Grate II (1 hopper), and Grate III (2 hoppers).

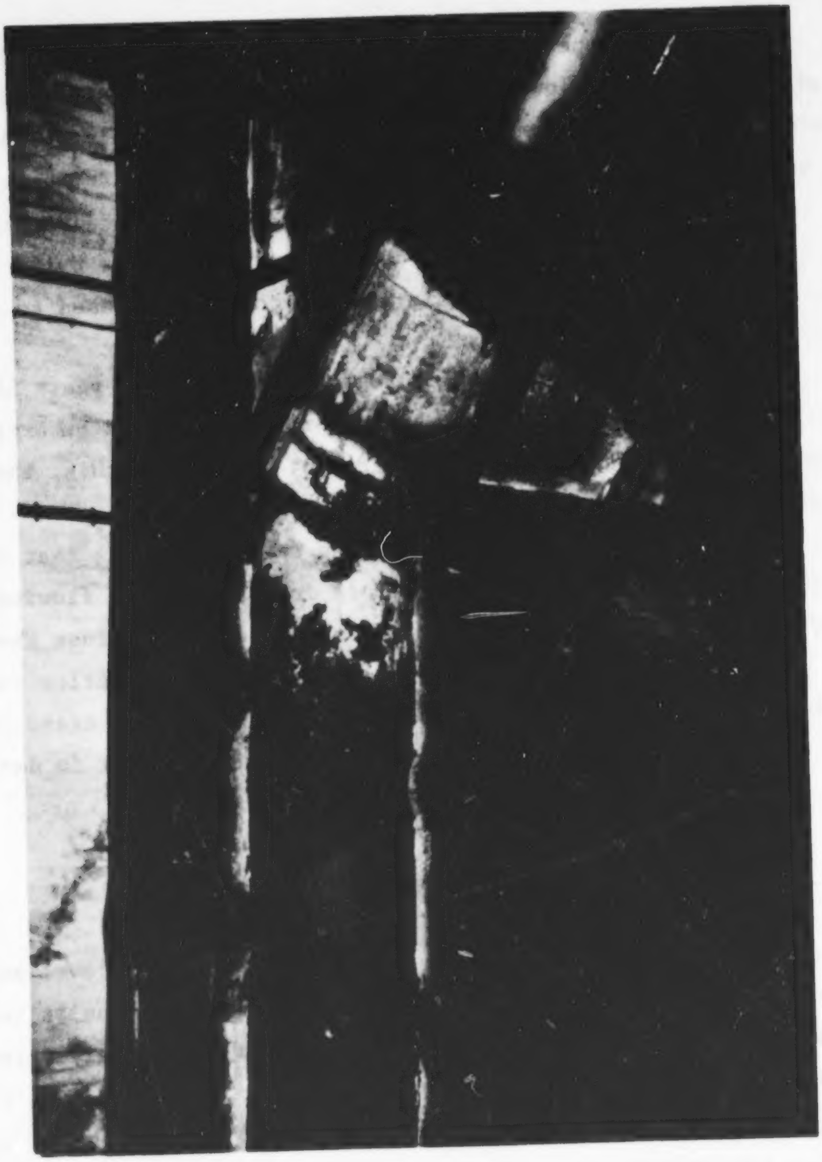


FIGURE 15-25. WARPED FEED CHUTE AT COPENHAGEN: WEST

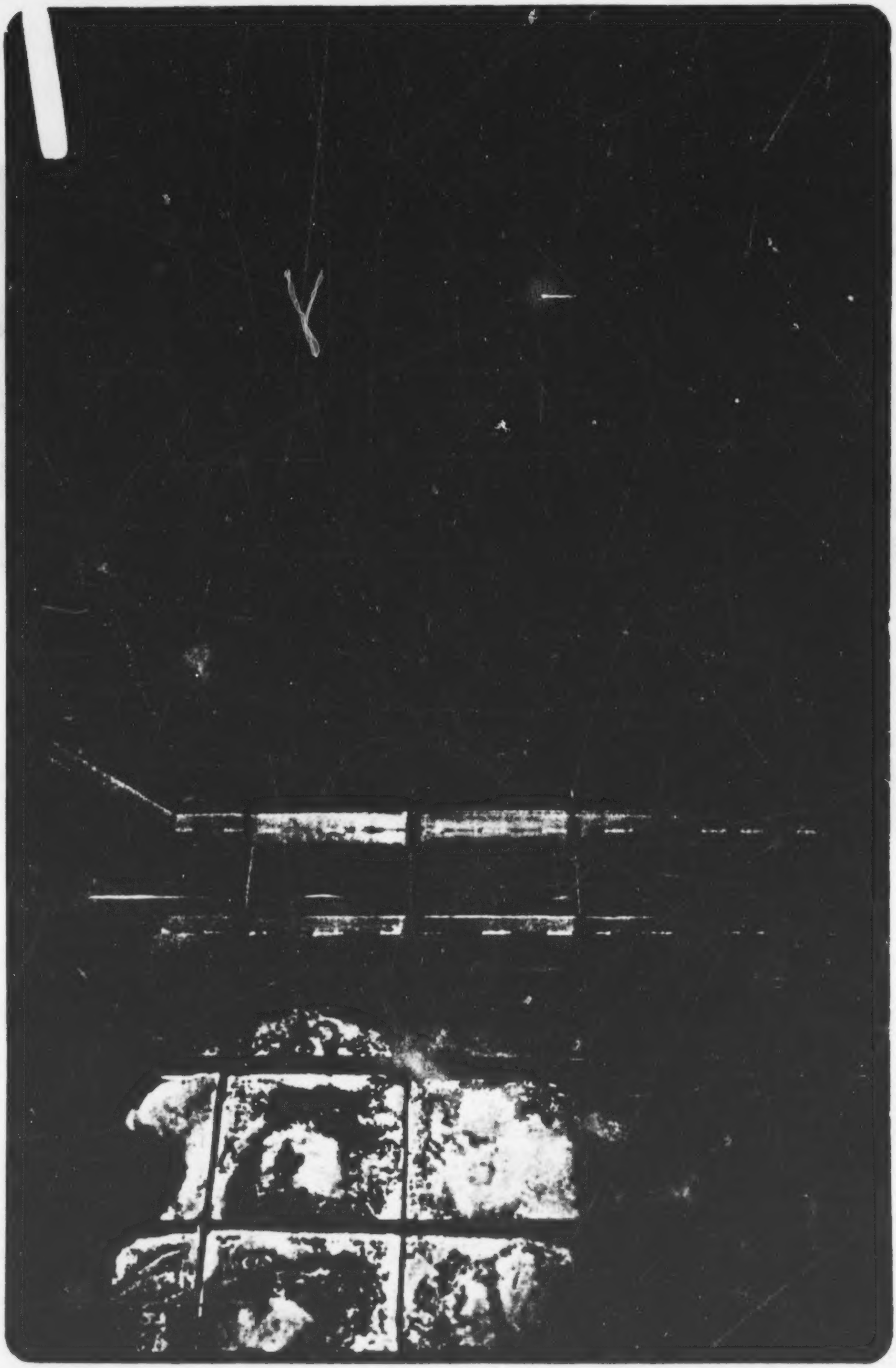


FIGURE 15-26. PEELED PAINT ON FEED CHUTE CAUSED BY BURNBACK. ALSO PRIMARY AIR FAN AT COPENHAGEN: WEST

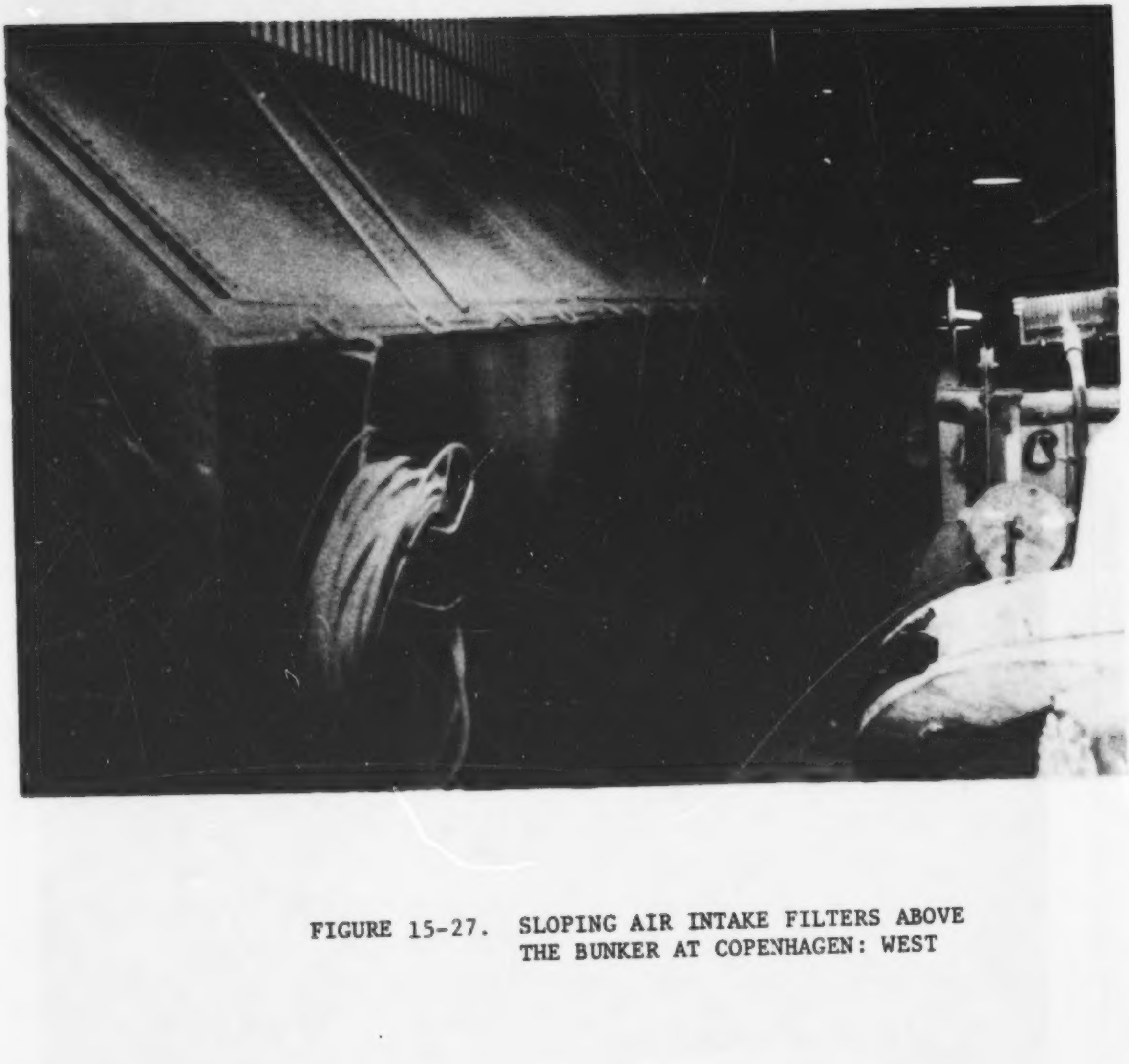


FIGURE 15-27. SLOPING AIR INTAKE FILTERS ABOVE THE BUNKER AT COPENHAGEN: WEST

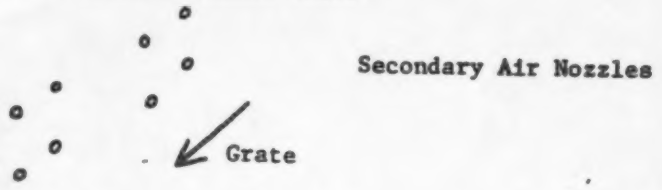
The Unit #4 fan is 20% larger than the fans for Units 1-3. Another West #4 difference is that primary air is delivered to a distribution box around the seal ring. In Units 1-3, the air is delivered directly to the seal ring.

Secondary (Overfire) Air - Boiler Room Cool Air

West Unit #4 is equipped with a normal fan which pulls 30 C (86 F) cool air from the boiler room and supplies it to the furnace as secondary overfire air. West also has hot flue gas recirculation fans as described in the next section.

The Nordisk Ventilator forced-draft 150 Hp belt-driven fan, running at 1,670 rpm, can pull 35,000 Nm^3/hour. The temperature is assumed to be 30 C (86 F) and the static pressure is 460 mm water.

West Unit #4 normally uses the boiler room cool air. The air is sent to two manifolds on each side of the furnace and above Grate III. Each manifold has four nozzles as shown below:



Secondary (Overfire) Air - Flue Gas Recirculation Hot Air

Where it is assumed that the net calorific value of the refuse may reach 2500 kcal/kg and over, the plants are installed with recirculation of flue gas as this means of temperature control are more efficient and cheaper. This is done to thermal shocks on refractory.

West Units #1-3, unlike Unit #4, use hot flue gas as secondary air. The air is drawn from the flue gas leaving the hot electrostatic precipitator. See Figure 15-28.

Another Nordisk Ventilator forced draft fan, this one at 150 Hp, is belt driven at 1460 rpm. The fan is rated at 45,000 Nm^3/hour and delivers the 300 to 350 C (572 to 662 F) hot flue gas at 220 mm water pressure (8.7 inches water).

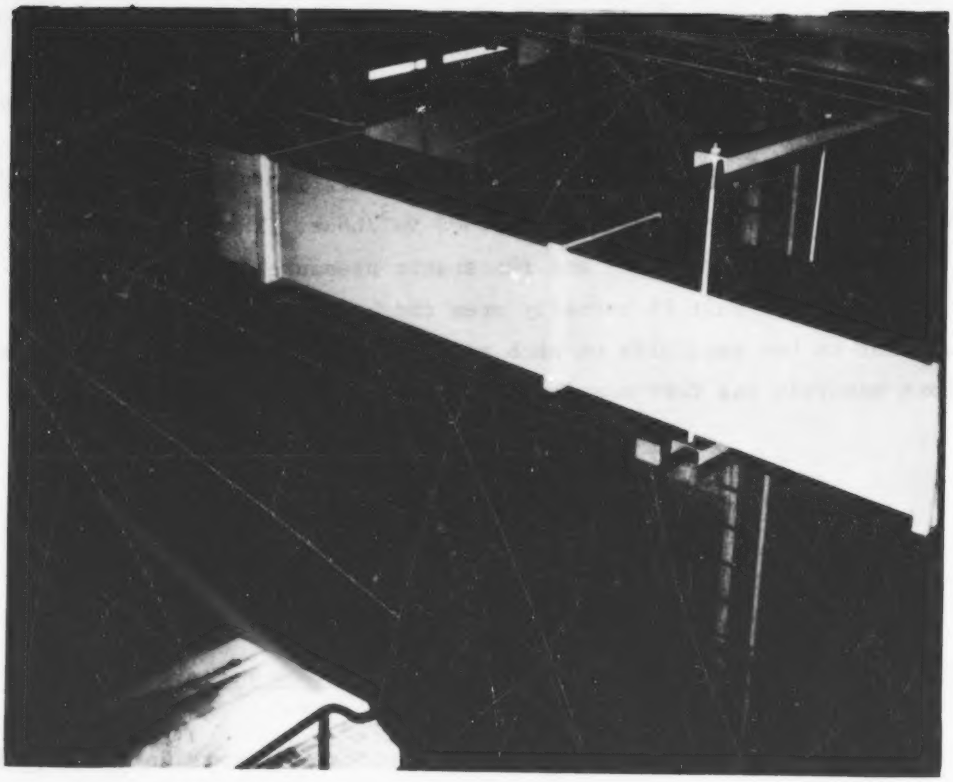


FIGURE 15-28. ROTARY KILN AND FLUE GAS RECIRCULATION DUCT AT COPENHAGEN: WEST

The use of ambient boiler room air at 30 C (86 F) or recirculated flue gas air, 536 to 662 C (280 to 350 F), is determined by basic furnace design and the refuse lower heating value (LHV). Assume that the furnace was nominally designed for refuse with a LHV of 2000 kcal/kg. If the LHV is well over 2000 kcal/kg, then cool ambient air, rich in O_2, might shock the refractory and cause the Carborundum bricks to grow and spall. Therefore, if the refuse is "hot", then warmer recirculated flue gas air, poorer in O_2, should be used. In contrast, if the refuse is "cool" or wet, then ambient boiler room air, rich in O_2, should be used.

At Amager, where the refuse is cooler at 1800 kcal/kg (3240 Btu/pound), they now use only ambient boiler room air. Refractory life has improved.

For the reason mentioned above, the calorific value also being lower than 2000 kcal/kg (3600 Btu/pound), the necessity of gas recirculation at West was not present and the ducts and fans for Units 1-3 were dismounted and stored.

Because of the low level of calorific value at the present, the Unit 4 was designed for recirculated gas, but the necessary elements/components were not purchased. This will be done only when the real necessity is present.

Of the European vendors visited, Volund is the only manufacturer known to us to use recirculated flue gas.

Other common information is discussed in the Amager report and will not be unnecessarily duplicated here.

The recirculation flue gas fan has a damper that is automatically controlled. It sends a larger or smaller quantity of flue gas back to the furnace depending on the furnace combustion temperature. The dampers are adjusted so that the furnace temperature is always 900 to 1000 C (1652 to 1832 F).

Flue Gas Fan

An induced-draft Nordisk Ventilator flue-gas fan is located between the electrostatic precipitator and the chimney. It is necessarily the strongest fan and can pull 107,000 Nm^3/hour with its 220 Hp motor. It too is belt driven but at a lower speed of 1010 rpm. It delivers the flue gas at 172 mm water pressure to the chimney. Flue gas temperatures range from 300 to 350 C (572 to 662 F). The fan has a damper connected with a regulator which holds the vacuum in the furnace constant at all times.

Fan Summary

Table 15-4 presents key design parameters for the four fans: (1) F. D. primary air, (2) F. D. secondary air, (3) I. D. flue gas, and (4) F. D. flue gas recirculation.

The plant people report that the four furnaces each with four fans have experienced only minor maintenance.

Assuming the maximum refuse calorific value to be 2,500 kcal/kg (4500 Btu/pound), the theoretical air is 3.01 Nm^3/kg (48.3 ft^3/pound) of refuse. The actual air is 4.5 to 6 Nm^3/kg (72.2 to 96.3 ft^3/pound). After combustion, the theoretical combustion flue gas is 3.78 Nm^3/kg (60.7 ft^3/pound) while the actual is 5.3 to 6.8 Nm^3/kg (85.1 to 109.1 ft^3/pound).

The Nm^3 should be defined at NTP (normal temperature and pressure) e.g., at 0^oC and 760 mm Hg. To find the actual m^3 at a certain temperature the following formula is used:

$$m^3 = \frac{273 + t}{273} \times Nm^3$$

where 273 is the absolute temperature, "t" the actual temperature in ^oC, and Nm^3 the m^3at NTP.

Furnace Combustion Chamber

The original Volund designers had two seemingly opposite design considerations. First, the design should ensure proper drying-out of the wet refuse. Therefore, there is a desire to use a gas counter-flow to the waste flow as shown in Figure 15-29a.

On the other hand, there should be good burnout of putrescibles and carbon. Therefore, the gas flow should parallel the waste flow as in Figure 15-29b.

TABLE 15-4. PRIMARY, SECONDARY, FLUE GAS AND RECIRCULATION FAN PARAMETERS

	Primary Air Forced Draft	Secondary Air Forced Draft	Flue Gas Induced Draft	Recirculation*
Fans per Furnace	1	1	1	1
Volume of Air (Nm^3/hour)	45,000	35,000	107,000	45,000
Static Pressure (mm Water)	230	460	172	220
Temperature (° C)	30	30	350	350
Fan Revolutions (rpm)	1,490	1,670	1,010	1,460
Belt Driving	yes	yes	yes	yes
Motor Power (Hp)	75	150	220	150

*System has been dismantled and stored.

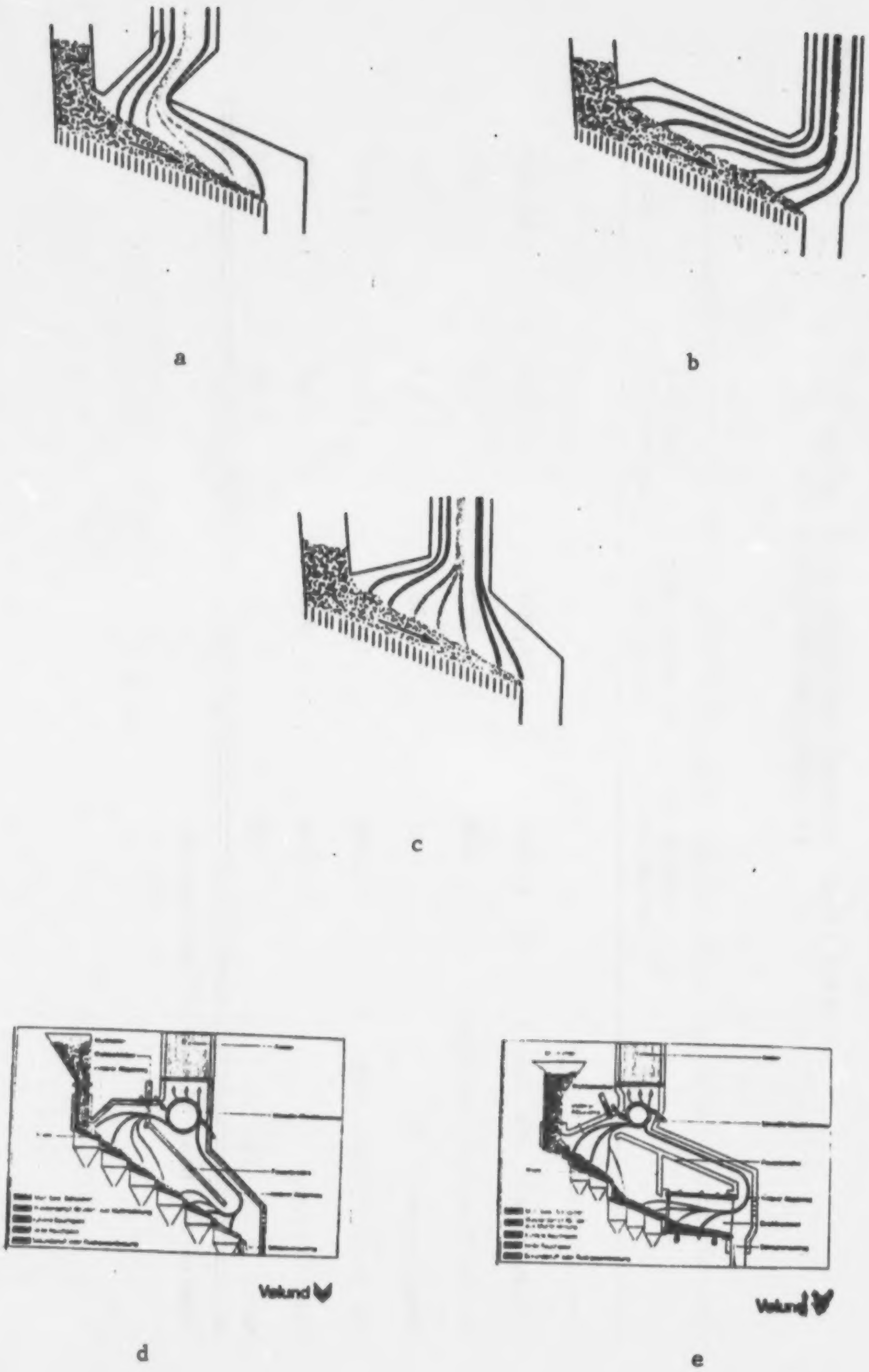

a
b
c
Volund
Volund
d
e

FIGURE 15-29. GENERAL DESIGN CONFIGURATIONS FOR VOLUND FURNACES

A compromise suggested by other vendors would be to simply compromise and have the flue gas exit centered over the grate as shown in Figure 15-29c.

The Volund simplified answer is to put a wall above the grate and to send some of the gases back toward the feed chute and the other gases toward the ash chute as shown in Figure 15-29d.

The more elaborate answer from Volund is to attach a rotary kiln at the end of the furnace grate as shown in Figure 15-29e. Here, some hot gas returns back toward the feed chute to help dry the incoming waste. Also, the other gases continue flowing with the waste out of the grate area and into the rotary kiln. The heat supports further combustion in the kiln to consume almost all of the putrescibles and unburnt carbon.

This configuration, known as the 2-way gas grate and rotary kiln system, is the design at both Amager and West. The schematic for Frederiksberg (1934) show the basic configurations. To restate, the original two Volund plants (Gentofte and Frederiksberg) successfully served Copenhagen for 40 years (Figure 15-30).

The volume of all space prior to the boiler is as follows:

Furnace Combustion Chamber	100 m^3
Rotary Kiln	73
Overhead By-Pass	50
Afterburning Chamber	125
	348 m^3

Burning Grate (Forward Pushing Step Grate)

Information, for the record, regarding the Volund grate is distributed between the trip reports #14 and #15 (Amager and West) i.e. information is being purposely not duplicated. Part of this section is taken directly from a technical paper written by Mr. E. Blach, former Volund Chief Engineer, entitled "Plants for Incineration of Refuse" - 1969. Figure 15- 31 shows the principle of a forward pushing step grate system Volund. Volund grate bars on a table are shown in Figure 15-32.

> This grate construction is built up of several grate sections, each separated by a vertical grate transition bar. The ratio of size between the individual grate sections and grate transitions is determined by the composition of the refuse.
>
> The individual grate section is built up of lengthwise-placed sections of 180-300 mm wide laid up with an inclination of 18-25°. Every other of these sections are fixed and every other are moveable, and each section is built up of a through grate bar, which is welded up, on which a number of grate blocks of

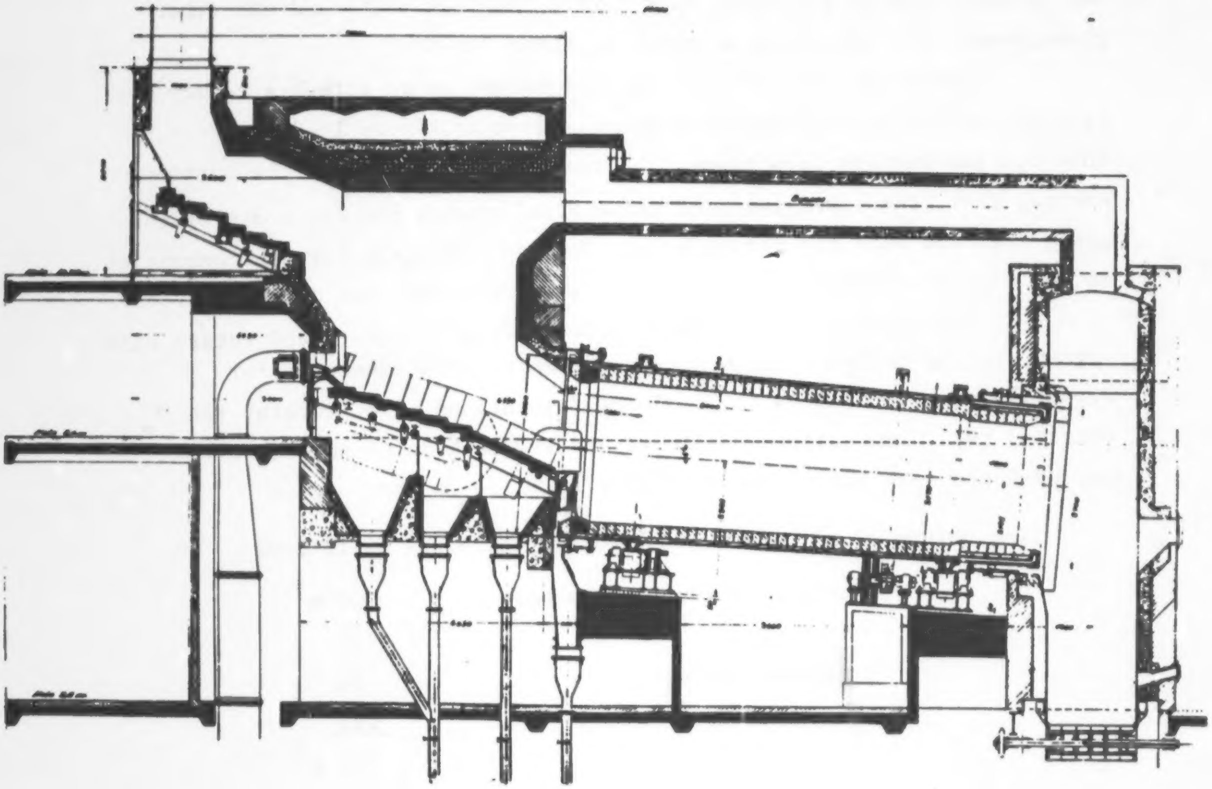


FIGURE 15-30. FURNACE DESIGN (TWO-WAY GAS GRATE AND ROTARY KILN) AT THE OLD (1934) FREDERIKSBERG PLANT, NOW DISMANTLED

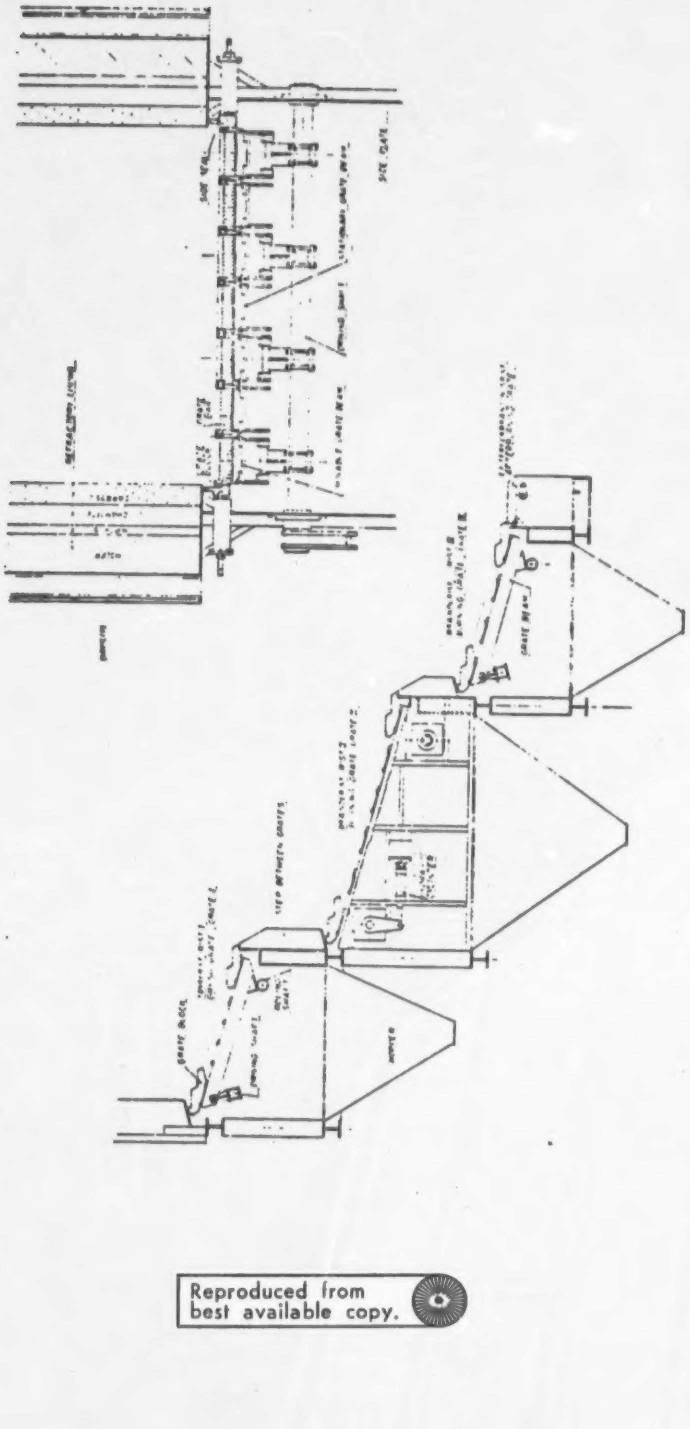


FIGURE 15-31. VOLUND'S FORWARD PUSHING STEP GRATE

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FIGURE 15-32. VOLUND GRATE BARS ON DISPLAY

specially alloyed cast iron are fitted, which are in turn filled up with loose grate bars of cast iron.

The moveable sections are driven hydraulically by a transverse driving shaft placed under the grate, which is connected to the individual sections by pendulum driving bars. From a neutral position the movement in forwards stroke is slowly raising, forward going and then lowering and backwards going. In the backwards stroke the movement is slowly lowering and backwards going and then raising and forwards going.

Along the side of grate sections, which are built into the wall of the furnace there are a number of side sealing beams, which through building in springs give the grate sections a transverse flexible assembling.

The first grate section acts as a feeding and pre-drying grate and apart from the last part of the transition bar it is covered with grate plates. Ignition and the first part of the combustion take place at the first transition and on the 2nd grate. The final combustion and burnout takes place on the 3rd grate, and calcining and cooling of the clinkers begin at the last part of the 3rd grate and continue on the subsequent clinker chute.

The layer of refuse is 300-500 mm. The moveable grate sections give a lifting, moving and turning movement in the lower half of the layer so that the combustion air, which in a regulated way is supplied from below, can get to all parts of the layer. At the transition bars there is a supplementary turning, mixing and air supply.

Volund supplies furnaces with either three or four separate grates. Vest has three grates per furnace. There are some important differences between Units #1-3 as compared with the newer Unit #4. Units #1-3 have long beams with pendulums and five (5) cylinders. Unit #4, however, has shafts with two (2) cylinders.

Each of the Units #1-3 furnaces has two operating hydraulic pumps. At some other installations, an additional hydraulic pump is used as a standby. Each pump's capacity is 47 liters/minute (12.4 gallons/minute).

Each pump has a 15 Hp motor. The resultant pressure is 75 kg/cm^2g (1160 $pounds/in^2$). The plant has one 600 liter (160 gallon) oil storage tank.

Each of the first three grates have five hydraulic cylinders with cylinder bases of 80 mm (3 inches) and strokes of 130 mm (5 inches). The stroke frequency is 3 strokes per minute.

Having three grates means that there are two steps. The height between Drying Grate I and Burning Grate II is 1 m (3 feet). Between Grate IV and Final Grate III the height is 2 m (6 feet). Some Volund systems (such as Roskilde, but not either West or Amager) have an afterburning Grate III. The afterburning grate is used only on grate type furnaces without rotary kiln and only when the waste to incinerate is of a difficult type demanding 20 to 30 minutes extra retention time to complete burn out.

The final step, from the grate system to the rotary kiln, is 1 m (3 feet) high. The grate exit to the rotary kiln is shown in Figure 15-33.

Plant officials estimate that the individual grate bars will last about 20,000 hours. Stated in another manner, 100% of the bars are replaced every 20,000 hours. Despite the Unit #4 being newer and simpler, the average run between breakdowns is longer for Units #1-3.

Compared to Amager, the amount of small sized inert (ash) particles is less at West. Perhaps West's fewer inerts, less grass, and less home furnace ash contribute to West's longer grate life.

Units #1-4 have the following configuration for the three grates per furnace. All grate frames, bars , and grates are made from "Meechanite HR." The side seals are made from "Nicromax". Nicromax has a composition of mainly 2/4 Cr/Ni based on 3.5 percent C, giving low tensile strength, but high Brinnel hardness and resistance to heat.

All three grates have a 2.7 m (8.9 feet) width. The length and area of the three grates are as follows:

	Drying Grate 1	Burning Grate 2	Burning Grate 3
Grate Length (m)	2.5	2	5
Area (m^2)	6.75	5.4	13.5

Furnace Refractory Wall

Volund furnace walls are refractory lined (and not lined with water tube walls) inside a steel framework. See Trip Report 14 on Amager for more design details.

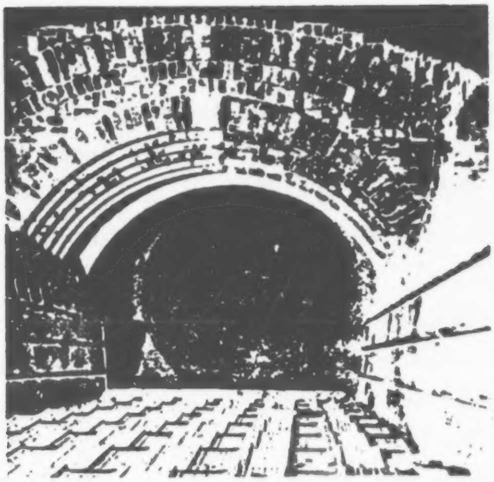

FIGURE 15-33. GRATE FURNACE EXIT INTO A ROTARY KILN AT ONE OF VOLUND'S PLANTS

The six furnaces for both Amager and West (three each) were designed and built at about the same time. Because of their initial problems, West Unit #4 was built differently and has performed better.

Volund originally chose Hoganus, a high-quality and expensive refractory, for its lining. The bricks themselves were not a problem. The difficulty, however, in Units #1-3 was that there were not enough anchors between the iron structural framework and the bricks.

In addition, furnace/boiler room air, cool and O_2-rich, was often used. Under certain conditions this would cause the silicon carbide refractory to grow and then spall 500 to 700 mm (1.5 to 2.3 feet) above the grate. The SiC oxidizes to SiO_2 and CO_2.

The first three units had to eventually be completely redone. More anchors were added. Secondly, the automatic furnace temperature system was reset so that more of the secondary air comes from the O_2 poor and warmer, 300 to 350 C, (572 to 662F) flue gas recirculation air. There was thus less secondary air from the O_2-rich and cooler 30 C (86 F) furnace/boiler room.

Based on the Hoganus problems at Amager and West, another refractory supplier, Junger and Grater, of West Germany was chosen. They made sure that there were enough anchors. Unit #4 anchors are at a density of 4 or 5 per m^2.

When asked about Kunstler (Zurich, Switzerland) air blocks, Mr. Jensleu mentioned that he did not know of them but he had heard many favorable things about Dr. Stein of the Didier Company in W. Germany. Kunstler uses perforated cast iron plates while Didier uses porous refractory blocks. Both provide evenly-distributed side wall tertiary air to prevent wall slagging close to the grates. Neither have been used at Amager or West as of 1977.

Figure 15-34 shows the exposed refractory brick wall after a section of slag has broken away.

Volund does not report the heat release area since the wall enclosures are not designed for heat transfer as are the walls of a water-tube wall furnace.

FIGURE 15-34. BROKEN AWAY SECTION AND SLAG ON WALLS AT COPENHAGEN: WEST

Rotary Kiln

The rotary kiln is seen in its relationship to other key furnace parts in a plant schematic of the now demolished Gentofte plant (see the previous Figure 15-8) that served northern Copenhagen so well for 40 years. The basic design (with the exception of major modifications to the boiler and air pollution control equipment) remains the same today. To repeat, again from Mr. E. Blach's paper:

> Pre-drying, ignition, and the first part of the combustion takes place on the grate system as described in the previous example, but then the refuse slides into the rotary kiln, where the final combustion and burning out takes place.
>
> While in operation the rotary kiln turns slowly and thus creates a perfect overturning of the burning refuse. The movement makes the refuse travel a very long way and thereby stay for a long time in the kiln. The system operates with the so-called divided flue gas/combustion air circulation, e.g. the primary combustion air is divided into two after having passed through the layer of refuse on the grates; one part passing through the rotary kiln and one part passing over the layer of refuse on the grates up to the top of the furnace, from where it is brought back to the after burning chamber through the previously mentioned connecting flue gas duct and here it is united and mixed with the gas coming from the torary kiln.
>
> Besides primary air secondary air is added over the grate sections as well as the rotary kiln in order to ensure for certain that the flue gases are fully burned. By adding a surplus of primary and/or secondary air a cooling of the combustion can be achieved. But this cooling function can be achieved better and more effectively by using a flue gas recirculation system, e.g., cooled flue gas is brought back

to the combustion zone, over the grates, and at the rotary kiln. While in operation, this cooling function is done automatically so that the temperature is kept at 900°-1000° C.

The rotary kiln is built up of an outer heavy steel plate, which lined with wear resistant fire-proof bricks on the inside laid up and built on an insulating layer direct up to the steel plate. At the ends the kiln is furnished with special sliding seals and transition sections and the whole construction rests on two sets of running and guiding wheels, which at the same time act as friction pinion, activated by hydraulic motors. The speed of rotation can be regulated variably between 0 and 15 r.p.h.

The grate/rotary kiln design is used for capacities from 5 t/h to about 20 t/h, but can be built also in larger plants.

The carbon steel shell (See Figure 15-35) has an inside diameter of 4 m (13.2 feet). With the addition of refractory, the inside diameter is reduced to 3.4 m (11.2 feet). Each kiln is 8 m (26.4 feet) long. Volund will build kilns up to 10 m (33 feet). The volume is 73 m^3 (2,578 ft^3).

The kiln is sloped downward at a 3 degree angle and revolves upwards of 12 revolutions per hour (rph). It however, normally revolves at 6 to 8 rph. If the furnace operator is told by the crane operator that the refuse is wet or if he sees a disturbance in the kiln on the TV monitor, he can easily lower the kiln speed (see Figure 15-36). The picture comes from the water-cooled closed circuit RV camera, manufactured by Philips N.V., (See Figure 15-37) that is continuously pointed from the lower end of the kiln. Figure 15-38 is a close-up of the West operating kiln looking toward the grate/kiln rectangular interface.

The support rings (2), support rollers (2), thrust roller (1), and the drive support rollers (2) are made from high tensile-strength steel castings.

An excellent burn in the grate at Itabashi, Japan results in a smokeless final burn in the rotary kiln as seen in Figure 15-39.

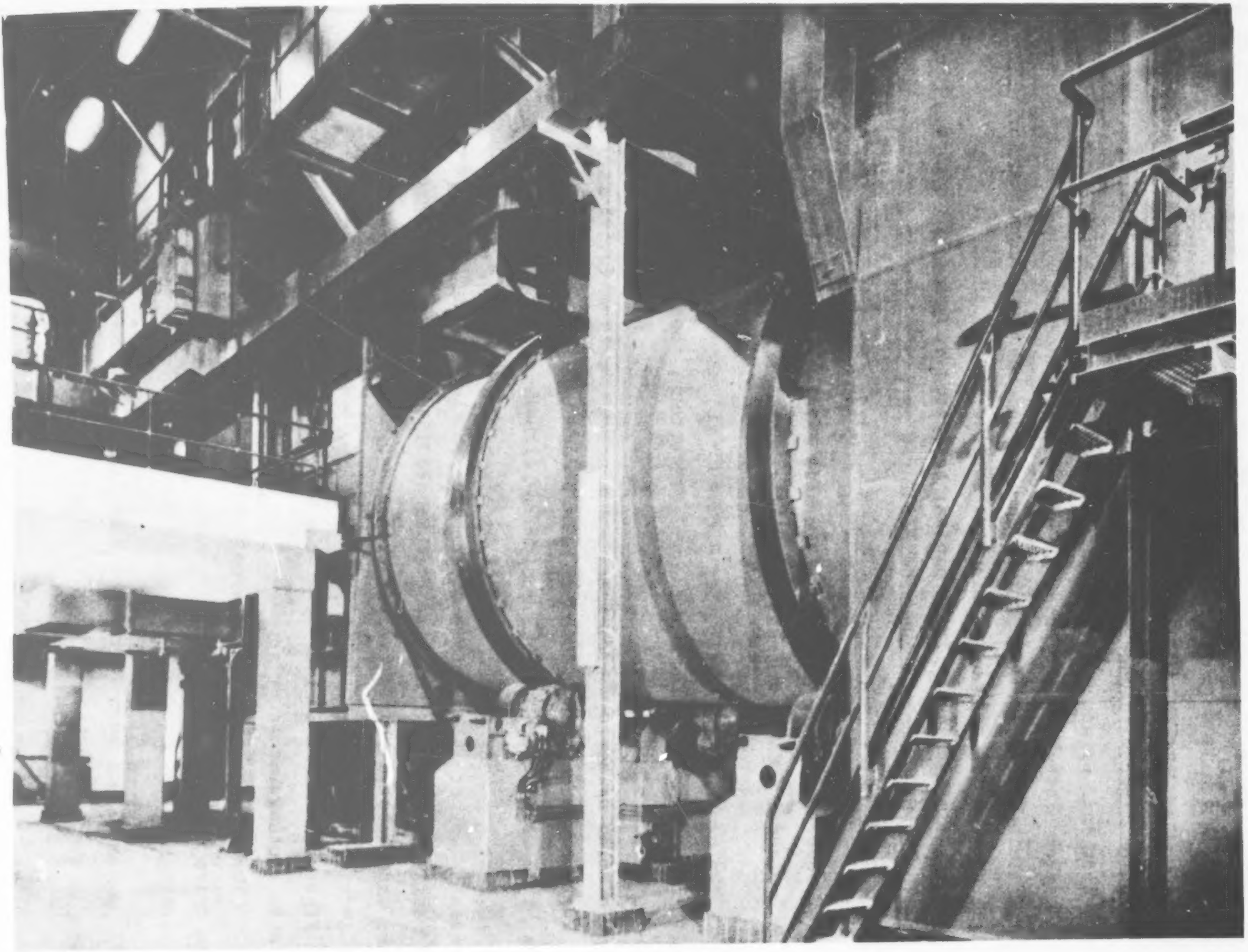

FIGURE 15-35. PICTURE OF THE VOLUND ROTARY KILN

FIGURE 15-36. CONTROL ROOM PANEL FEATURING TELEVISION VIEW OF ROTARY KILN AT COPENHAGEN: WEST

FIGURE 15-37. WATER-COOLED CLOSED CIRCUIT TELEVISION CAMERA LOOKING AT THE ROTARY KILN FIRE

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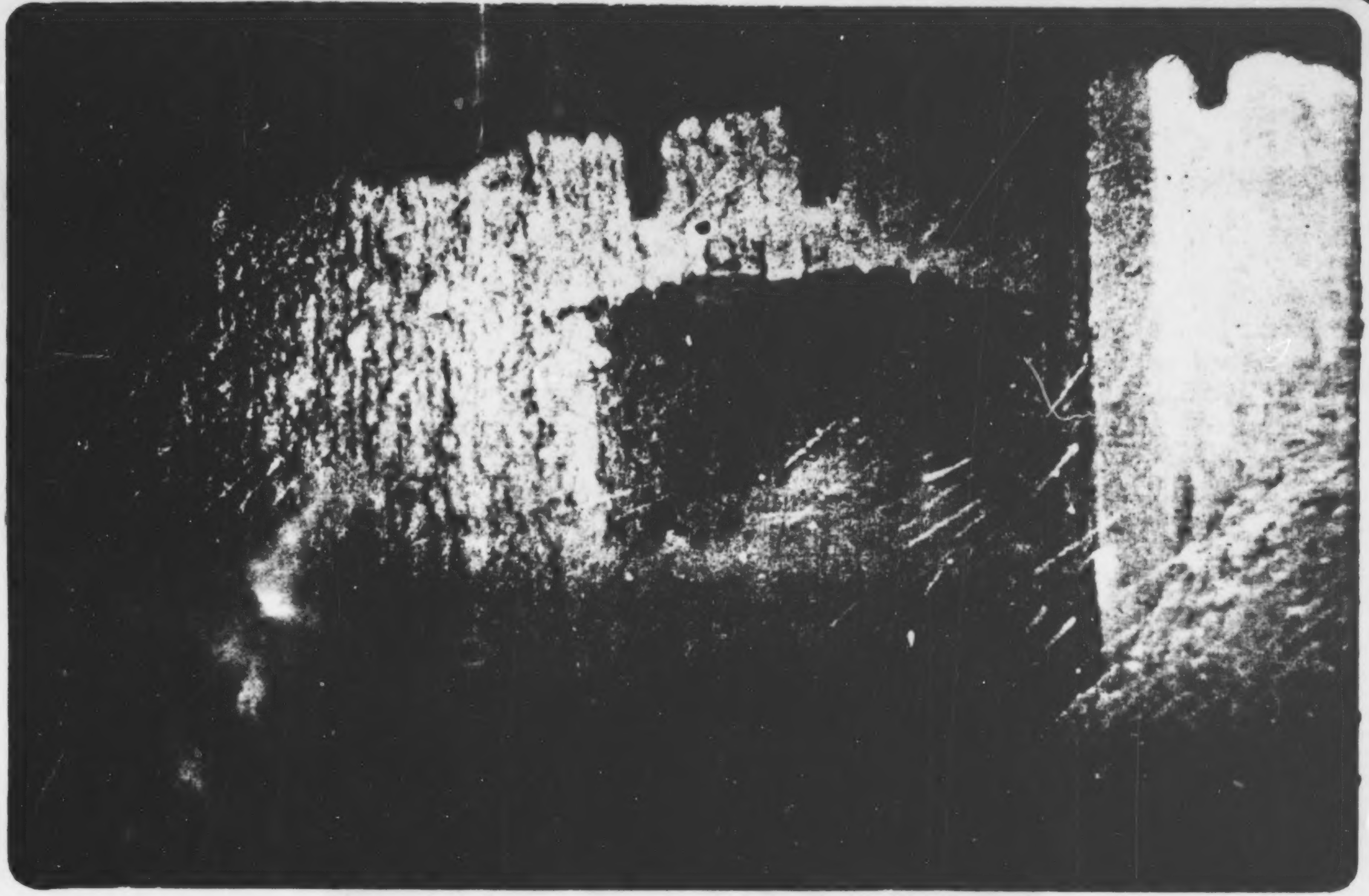

FIGURE 15-38. VIEW INTO ROTARY KILN TAKEN FROM LOWER END. SEE DISCHARGE FROM GRATE FURNACE, AT COPENHAGEN: WEST

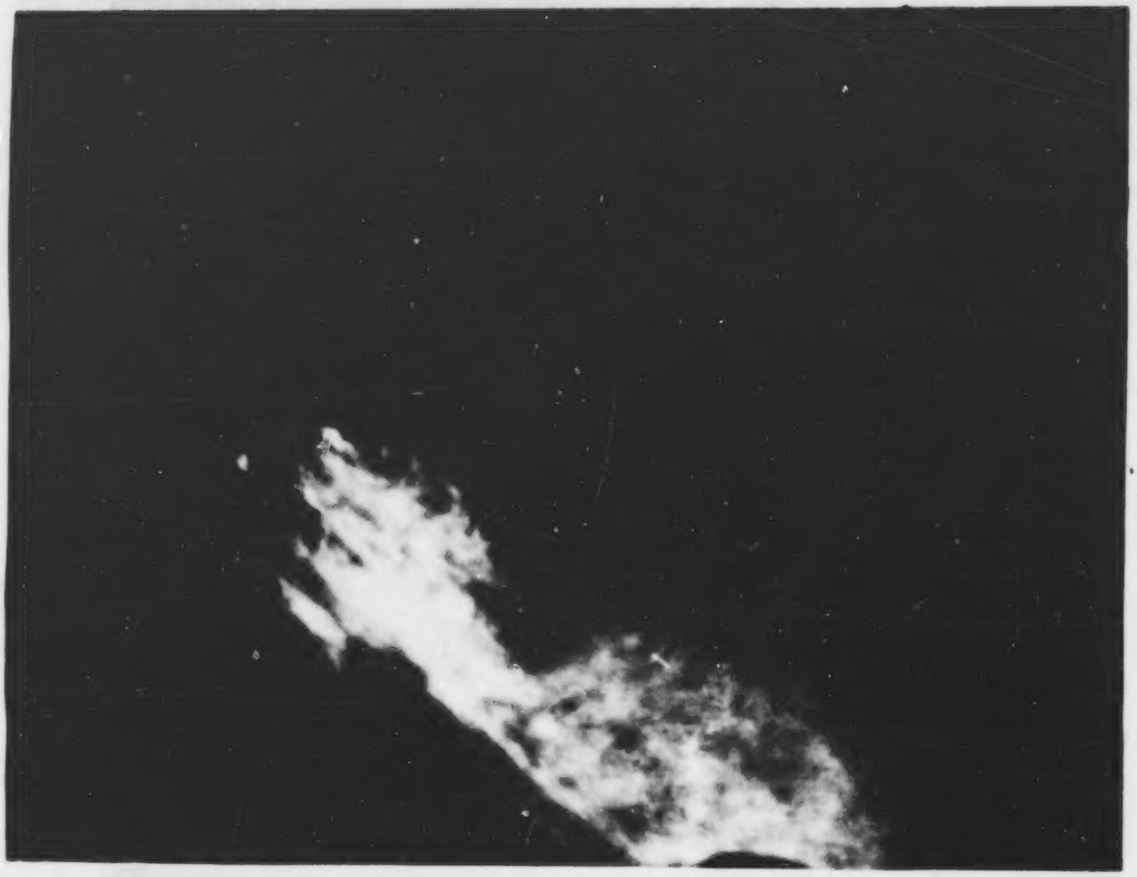

FIGURE 15-39. VIRTUALLY SMOKELESS BURN IN VOLUND ROTARY KILN AT ITABASHI, JAPAN

The two hydraulic motors per kiln are rated at 3 kg-m (7.26 foot-pounds) and have a maximum speed of 76 revolutions per hour or 1.27 rpm. The nominal reduction is 1:800.

The refractory bricks are anchored onto the steel shell. Moler refractory is placed next to the steel shell. Then next to the Moler refractory, Chimotte bricks of varying alumina and silica content (36 to 55 percent Al_2O_3) are used to line the inside of the kiln. The composition is 85 percent SiC at the inlet.

To some extent, because of very high temperatures, the kiln is self-cleaning. Slag does not normally accumulate on refractory walls. However, at some other Volund plants having very hot conical kilns, slag "rings" occasionally from within the kiln. Interestingly, this ring can gradually move down the length of the kiln. It eventually disappears.

While not used at West, chemicals can be used to clean the kiln.

After Burning Chamber

Flue gas leaves both the grate section in an upward direction while flue gas also leaves the kiln and rises. Occasionally (and during the Battelle visit) slag will form on the 45° slanting lower surface in the mixing chamber. Three men were observed for at least a day while they removed slag. Apparently, a thermocouple had been installed in the wrong place and therefore did not record the very high temperatures in the chamber.

Boiler (General)

West and Amager have boilers completely separate and following the combustion furnace. The units are refractory walled furnaces followed by the boilers, i.e. Volund units are not "water wall incinerators/boilers". The boilers at West and Amager are of Volund type, designed and constructed by Volund. In time they found the Eckrohr type boiler suitable for incinerator plants and these are an integral part of the new Volund plants like in Japan and in the new Aalborg plant. The Eckrohr (translated "corner-tube") boilers were built under a license from Professor Dr. Vorkauf of Berlin, W. Germany.

When asked why the Eckrohr boiler is now used instead of the formerly specified Volund boiler, the reply evoked the Eckrohr features - features that seemed popular in several other places over Europe. (One estimate suggests that 180 Eckrohr boilers follow furnaces of various manufacturer's designs).

1. The four corner tubes are used not only to carry down-stream water but are also the structural support for the whole boiler. This reduces construction costs.
2. The heat transfer rate is excellent.
3. The circulation pattern is good.
4. It has high efficiency.
5. It is a natural circulation boiler.

The market for energy demands slightly higher temperatures at West than at Amager as follows:

	West	Amager
Energy form	overheated water	hot water
Water temperature leaving plant	160 - 170 C	115 - 120 C
Water temperature returning to plant	140 C 284 F	70 C 158 F
Heat output	21.5 gcal/hour	20 gcal/hour
Pressure (working)	16 kg/cm^2 225 psi	6 kg/cm^2 85 psi

The key reason for higher temperatures at West is that an early customer was the Copenhagen County Hospital that needed hotter water for sterilization and air conditioning.

The amount of combustion gas entering the boiler was provided but as a function of refuse lower heating values.

	Lower heating Value kcal/kg	Amount of Gas Nm^3/hour
Lowest	1000	33,000
Average	2000	77,000
Highest	2500	98,500

The combustion gas inlet temperature to the boiler is around 800 C (1472 F). The outlet combustion gas temperatures range from 280 to 350 C (536 to 662 F).

The boiler of Unit #4 has 54% more heating surface area than each of the Units #1-3: 1598 m^2 (17,194 ft^2) compared to 1,115 m^2 (12,000 ft^2). Details as given are shown below with the codes also appearing in Figure 15-40.

Units #1-3

First Pass Radiation Wall	115 m^2
Second Pass Radiation Wall	99
Third Pass Radiation Wall	87
Regular Radiation Walls	301
Scott Walls	29
Total Radiation Walls	330
Convection Section	330
Economizer Section	455
Total Heating Area	1,115 m^2

Figures given for Unit #4 are not as detailed:

Unit #4

Radiation Pass No. 1	121 m^2
Radiation Pass No. 2	164
Scott Walls	125
Turning Chamber	96
Convection Surface	621
Economizer	471
	1598

The "Scott Wall", not found in many boilers, is a wall of tubes in the middle of a pass. Its purpose is to collect more heat, to help reduce gas temperature, to increase residence time, and to redirect flue gases to the hoppers so that more flyash falls out.

Plant officials have been happier with Volund's Unit #4. It can process 14 tonnes (15 tons) per hour. The dust accumulation on the tubes is lower and the boiler is easier to clean. The operational availability is better and there have been longer run times.

Volund officials pointed with pride to the lack of corrosion in any of the four furnaces over the seven year period.

	Units #1-3	Unit 4
Hours per year performance	6,500	6,500
Years of operation	x7	x2
	= 45,500	13,000
Number of Furnaces	x3	x1
Hours without corrosion failure	136,500	13,000

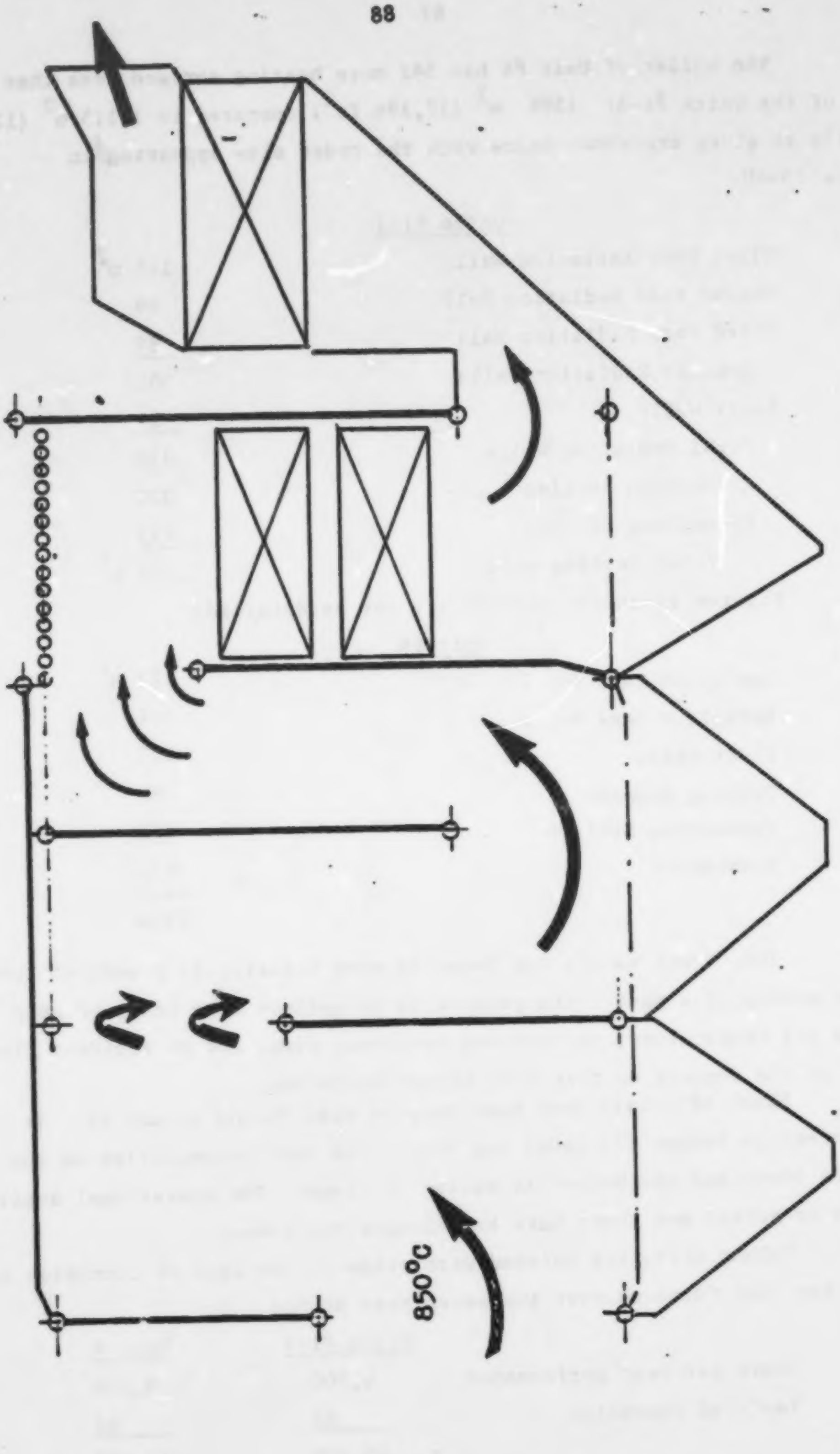
850°C
VOLUND

FIGURE 15-40. VOLUND BOILER SCHEMATIC AT COPENHAGEN: WEST

Mr. Pinto referred several times to their corporate position of not participating in the municipal waste "direct firing: to very high temperature steam" systems, i.e. above 350 C (662 F). They will not sell anything that would likely have corrosive failures within a year or two. As Mr. Pinto stated, "It's not fair (to the customer) to build a system that might fail".

The highest temperature steam directly achieved (in 1979) from Volund municipal refuse burning plants is 285 C (545 F) steam at the Boras, Sweden plant. The highest temperature in any of the Volund plants is 490° C (914 F) at Ortvikens Papperbruk, Sundsvall, Sweden. The plant, which is mainly for bark incineration, is equipped with an Eckrohr boiler producing steam at 425° C (797 F). In a separate overheater the temperature is brought up to 490° C (914 F) at 67 ato (985 psi).

Volund has six steam generating plants as listed below:
Sundsvall, Sweden-steam: 28.5 t/h - 67 ato - 490° C
Itabashi, Japan - steam 28.9 t/h - 16 ato - 203.4° C
Nishinomiya, Japan - steam: 14.6 t/h - 18 ato - 208.8° C
Kawagushi, Japan - steam: 15.8 t/h - 16 ato - 203.4° C
Kohnan, Japan - steam: 35.9 t/h - 16 ato - 203.4° C
Boras, Sweden - steam: 16.5 t/h - 10 ato - 285° C

If a customer wanted excellent burnout rates, wanted 500 C (932 F) steam, and showed high interest in Volund; then Volund's licensee would likely submit a bid. Volund might propose to raise the steam temperature to 350° C (662 F) by burning refuse. The steam would then be input to a topping off fossil fuel (likely oil) boiler to raise it to the 500 C (932 F) level demanded.

Economizer

The economizer and its steel shot cleaning system (Figure 15-41 and 15-42) both were supplied by Eckstrom of Stockholm, Sweden. As at Amager, the West exonomizers were fin tube with small spaces. The spaces and corners became so clogged with flyash and steel shot, that they will have to be replaced. Because of the clogging, the economizers at both

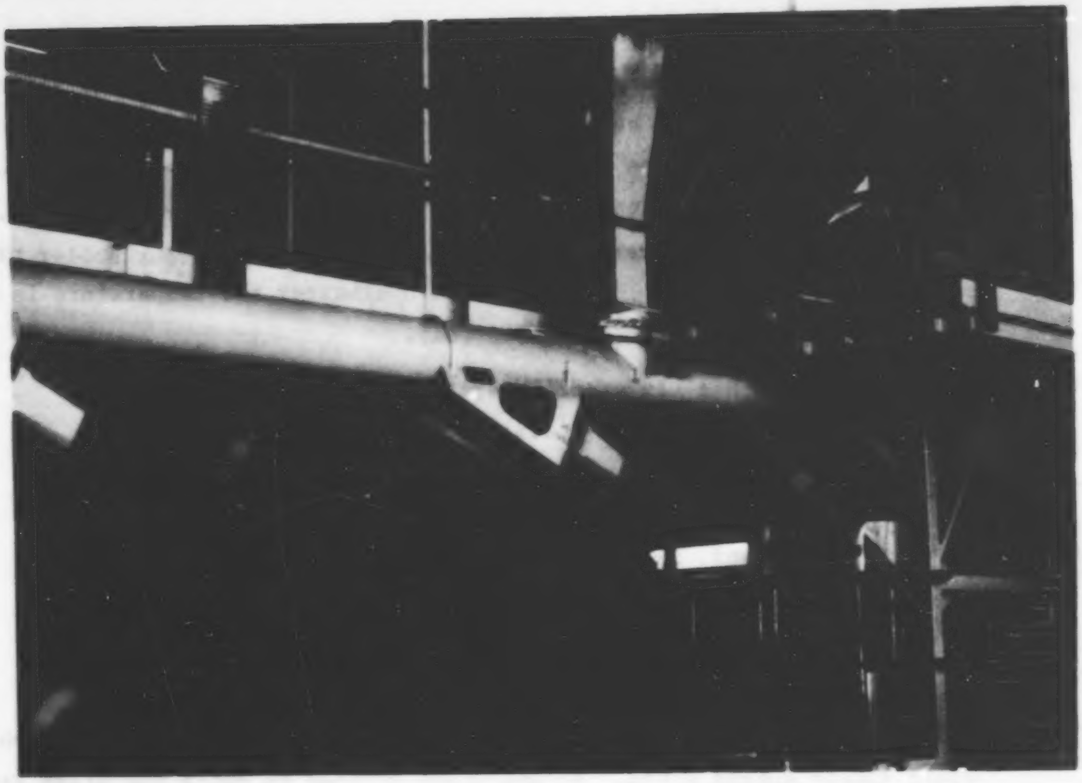

FIGURE 15-41. VIBRATING CONVEYOR FOR STEEL SHOT USED IN BOILER CLEANING AT COPENHAGEN: WEST

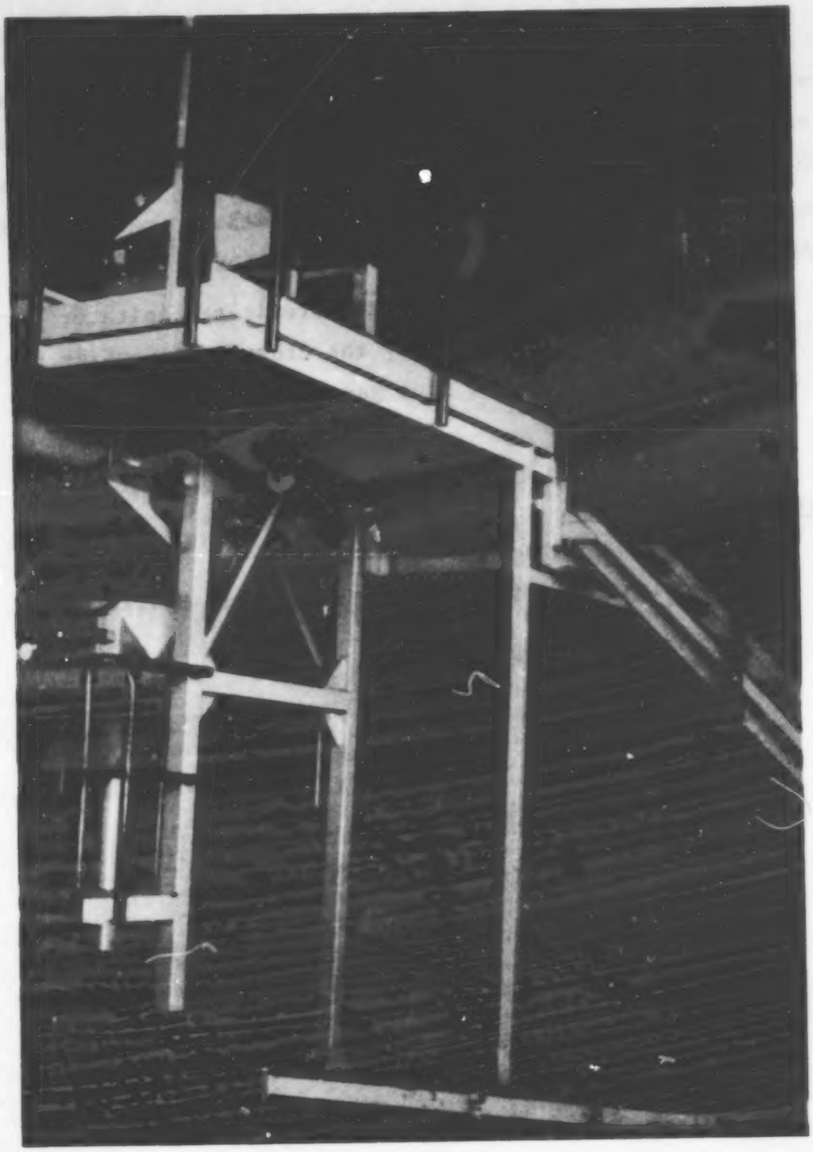

FIGURE 15-42. STEEL SHOT HOPPER ABOVE THE BOILER AT COPENHAGEN: WEST

Amager and West have set the overhaul schedule for the whole plant. Until the economizers are replaced, the unit will continue to shutdown every 1,500 to 2,200 hours. The manufacturer's original recommendation of cleaning every 3,000 hours would have been mainly to restore efficiency. The economizer is cleaned manually with brushes.

It is likely that the electrostatic precipitator corrosion problems experienced were caused by the clogged economizer not doing its job, i.e. lowering economizer flue gas exit temperature to below 300 C (572 F).

Boiler Water Treatment

The plant deoxidizes boiler water with Hydrazine.

ENERGY UTILIZATION EQUIPMENT

West produces superheated water at 160-170 C (320 to 338F) at 16 kg/cm^2 (228 psi). . As stated before, this is at a higher quality than the hot water at Amager because the key customer, the Copenhagen County Hospital had already planned its utilities as follows:

- Hot water into radiators for space heating,
- Hot water into the heat transfer device to make steam for use in the sterilization autoclave,
- Hot water into the absorption chiller to make cold water for air conditioning in the summer.

As is true of most waste-to-energy developments, the large charter energy user has much influence over plant design. The hospital location, along with the other current (1977) customers. is shown in Figures 15-43 and 15-44a. The network is basically a long main pipe, 6,000 m (3.75 miles) with several small branches.

There are no single family homes on the systems at present. However, officials are open to supplying hot water to associations of homeowners at a later date. When new customers join the service and the plant increases the heat production, the pipe line is already in place to take the necessary capacity. A school on the system is shown in Figure 15-44b.

Assuming that a single family homeowners association were to desire service, the association would have to obtain 50% participation before it would be worthwhile putting in additional piping capacity. A second condition would be the likelihood of eventually raising to 70% of the single-family homes in a contiguous area.

There is more of a tradition favoring district heating of single-family homes in the western Jutland peninsula than around Copenhagen. Actually, the company has not tried to get homeowners associations because the main pipe cannot carry any more heat.

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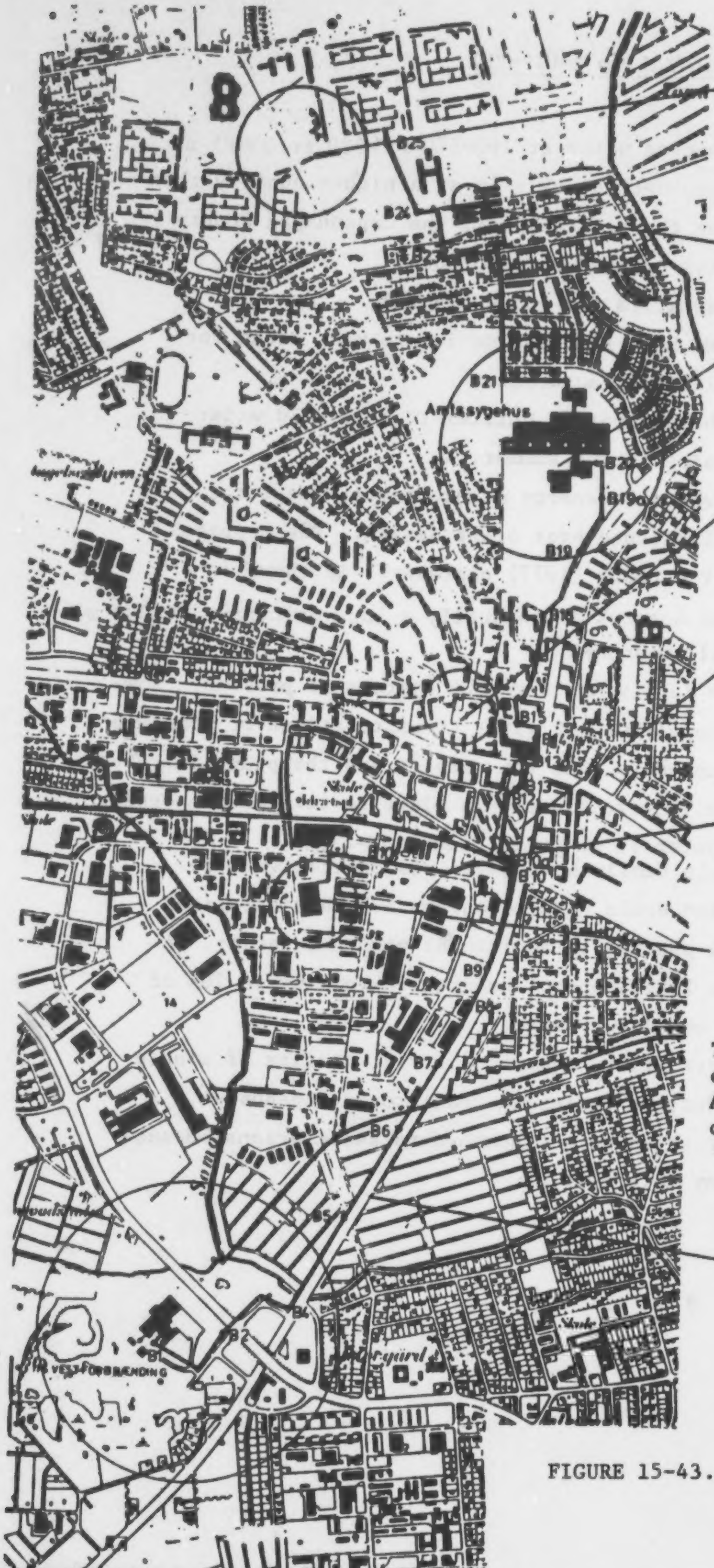
EXISTING DISTRICT HEATING NETWORK 1976/77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B6
B5
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B1
VESTFORBRÆNDING

Lille Birkholm Heat Co. a.m.b.a.

about 2000 apartments, nursing homes, a school, etc.
19 Gcal/hr

Køllegaard-Dyrholm School

1,2 Gcal/hr

Copenhagen County Hospital

35 Gcal/h up to about 45 Gcal/hr in 1985. Summer heat consumption for cooling

Herlev District Heat Co.

Shopping Center, City Hall, Library, School, Apartments, etc.
6,5 Gcal/hr

Near the RR-station -- RR Ground

Apartments

2,3 Gcal/hr
Connected in mid-77 1977)

Private Bank

0,24 Gcal/hr

Copenhagen County Pharmacy at Herlev, under construction

6,5 Gcal/hr

The main pipe has a transport capacity of 140 Gcal/h. (555 million Btu/hr) At the moment, only 50% of this capacity is used.

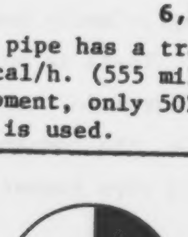


FIGURE 15-43. MAP SHOWING DISTRICT HEATING CUSTOMERS

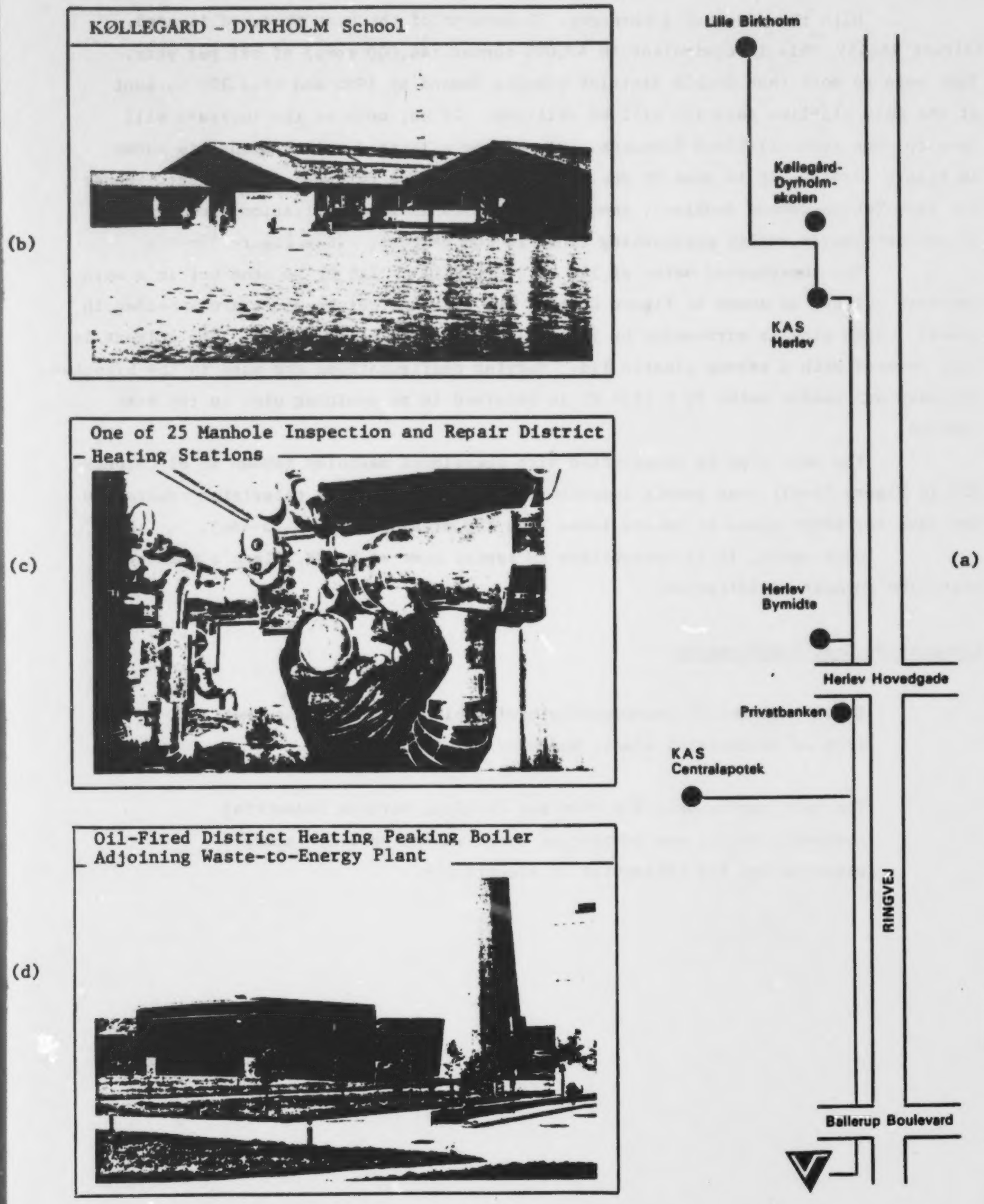

KØLLEGARD - DYRHOLM School
(b)
One of 25 Manhole Inspection and Repair District Heating Stations
(c)
Oil-Fired District Heating Peaking Boiler Adjoining Waste-to-Energy Plant
(d)
Lille Birkholm
Køllegård-Dyrholm-skolen
KAS Herlev
(a)
Herlev Bymidte
Herlev Hovedgade
Privatbanken
KAS Centralapotek
RINGVEJ
Ballerup Boulevard

FIGURE 15-44. DISTRICT HEATING SYSTEM AT COPENHAGEN:WEST

With the original 3 furnaces, 73 percent of the heat produced is used. (Figure 15-45). This is equivalent to 40,000 tonnes (44,000 tons) of oil per year. They hope to more than double district heating demand by 1985 and thus 100 percent of the main pipeline capacity will be utilized. If so, much of the increase will have to come from oil-fired furnaces. One of the oil-fired boiler plants is shown in Figure 15-44d. It is next to the chimney at the West refuse-burning plant. Under the plan (where demand doubles), the refuse-derived energy utilization could rise to 85 percent--never really approaching close to 100 percent. (See Figure 15-46).

The superheated water at 160 to 170 C (320 to 338 F) is sent out in a main concrete culvert as shown in Figure 15-47. The exit and return pipes are imbedded in gravel. Each pipe is surrounded by 100 mm (4 inches) of mineral wool. The culvert is then covered with a strong plastic lid. Varying configurations are used in the branches. The used and cooler water 70 C (158 F) is returned in an ajoining pipe in the same culvert.

The main pipe is constructed with occasional manholes (shown as B1 through B25 in Figure 15-43) that permit inspectors to run cylinderical television cameras up and down the water pipes to locate leaks (see the previous Figure 15-44c).

Once again, it is appropriate to repeat some of Mr. E. Blach's comments, this time on heat exploitation:

Comments on Heat Exploitation

> It will always be economically profitable to exploit the heat from an incinerator plant, whenever possible.
>
> The heat can be used for district heating, various industrial purposes, drying and burning of sewer sludge or other sludge products and for production of electricity.

Yearly Heat Consumption in 1976/77 (actual status quo)

Distribution of Heat: Production and Consumption

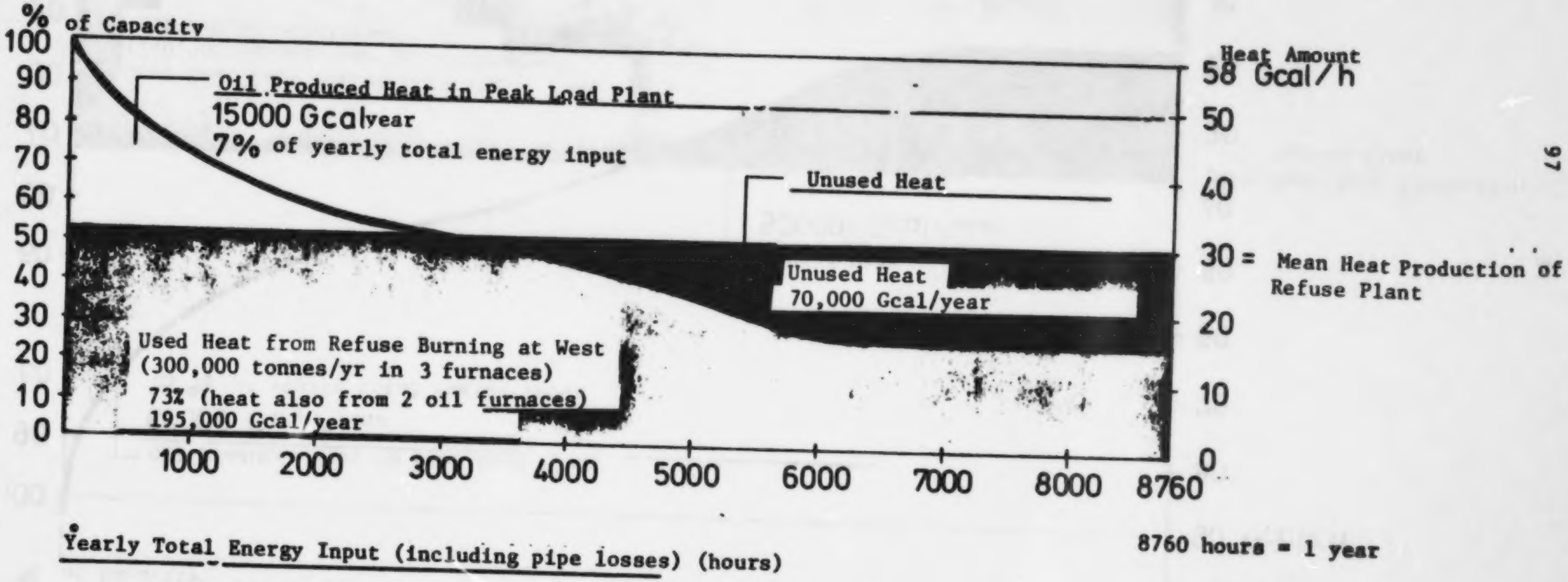


FIGURE 15-45. ACTUAL DISTRIBUTION OF HEAT: PRODUCTION AND CONSUMPTION AT WEST DURING 1976/77

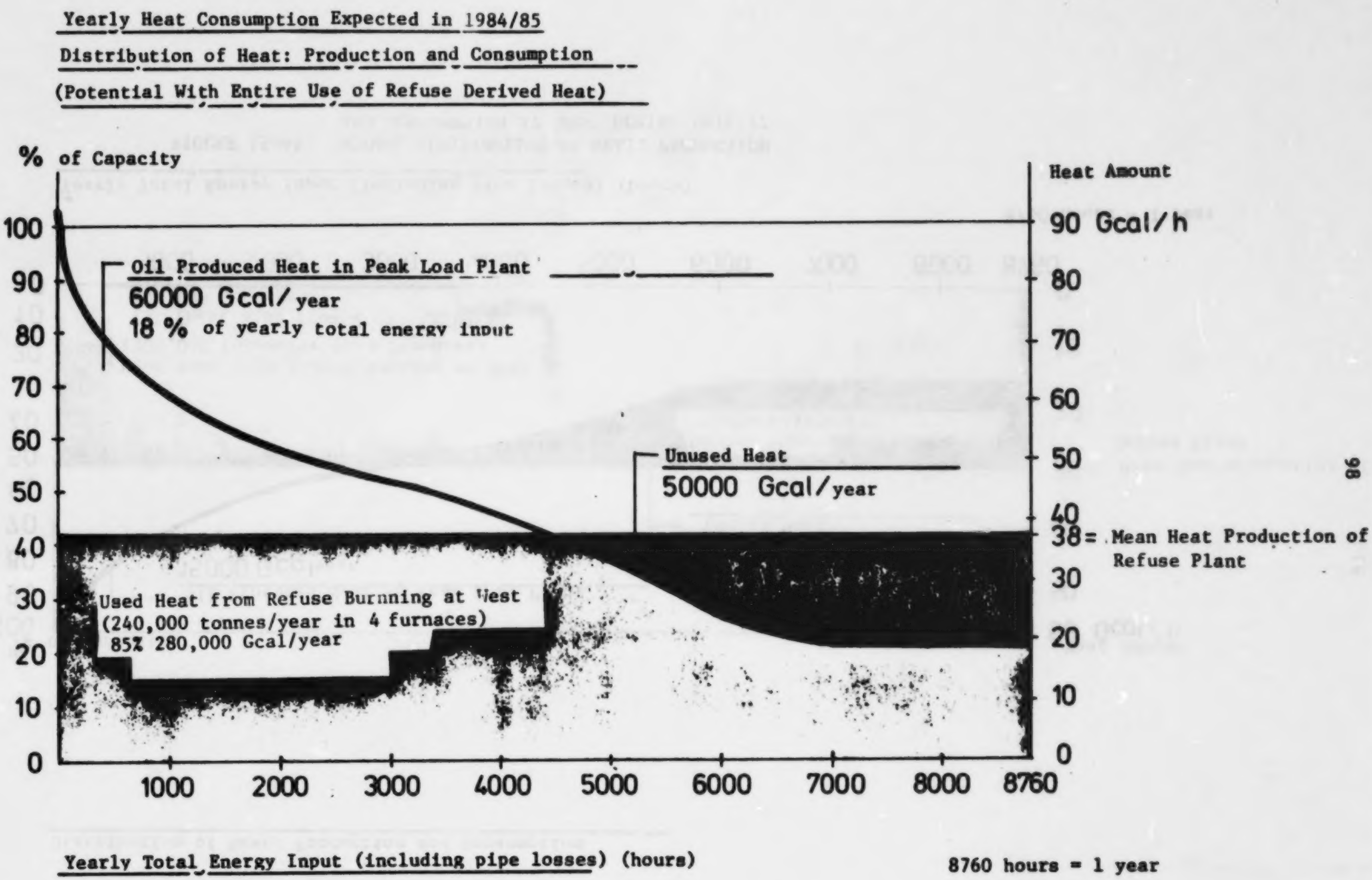


FIGURE 15-46. POTENTIAL DISTRIBUTION OF HEAT:
PRODUCTION AND CONSUMPTION AT WEST 1984/85

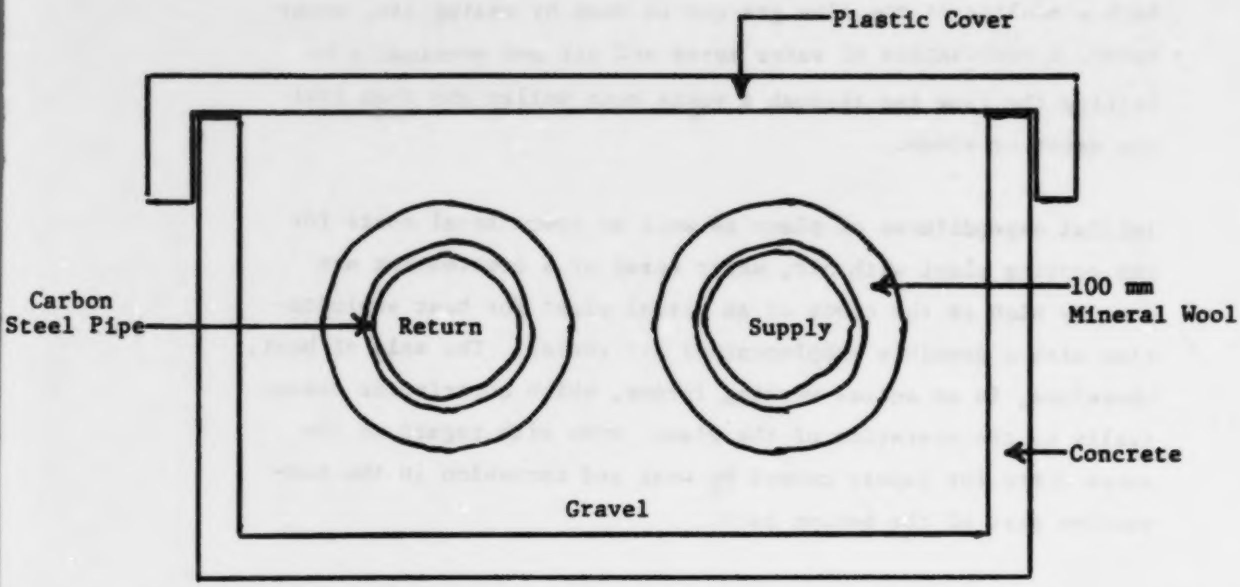

Plastic Cover
Carbon Steel Pipe
Return
Supply
100 mm Mineral Wool
Concrete
Gravel

FIGURE 15-47. DISTRICT HEATING PIPE TUNNEL AT COPENHAGEN: WEST

If the heat cannot be exploited other arrangements must be made to cool the 900-100°C, hot flue gas to below 350 C, before it is led into the precipitator and the chimney.

Such a cooling of the flue gas can be done by adding air, water spray, a combination of water spray and air and eventually by letting the flue gas through a waste heat boiler and then cool the water or steam.

Initial expenditures of plant as well as operational costs for the cooling plant with air, water spray or a combination are just as high as the costs of an actual plant for heat exploitation with a possible supplementary air cooler. The sale of heat, therefore, is an actual working income, which contributes essentially to the operation of the plant, even with regard to the extra costs for repair caused by wear and corrosion in the convection part of the boiler part.

Least profitable is the production of electricity as the costs of high pressure boilers and turbines are too high and the efficiency too low compared with the low price at which the big power stations can produce the electricity. There is a great need for drying and burning sludge and the use of waste heat for the purpose can be expected to be common in the future. Sale of heat for district heating or industrial purposes has, therefore, up to now been the solution which technically and economically has shown the best results.

The monthly pattern, of energy demand and production is shown in Figures 15-48 a and b; the difference being 3 furnaces versus 4 furnaces.

Figures 15-49 and 15-50 are maps showing the status-quo (1976-1977) and the planned (1984-1985) energy distribution pattern.

The "light" areas are the connected customers of high temperature water (160-170° C), while the "dark" areas are the secondary systems using low temperature water through heat exchangers (90° C).

The square signature means peak load stations equipped with oil fired boilers.

The round signature means heat exchanger stations.

The situation now and planned can be summarized as follows:

	1976/77	1984/85
Incinerator furances/boilers (on line)	3	4
Incinerator furnace/boiler (in reserve)	1	1
Total Incinerator furnace/boilers	4	5
Oil Fired Boilers	2	4
Total Capacity	58-60 G cal/hour	90-110 G cal/hour
Yearly Consumption	210,000 G cal/hour	340,000 G cal/hour

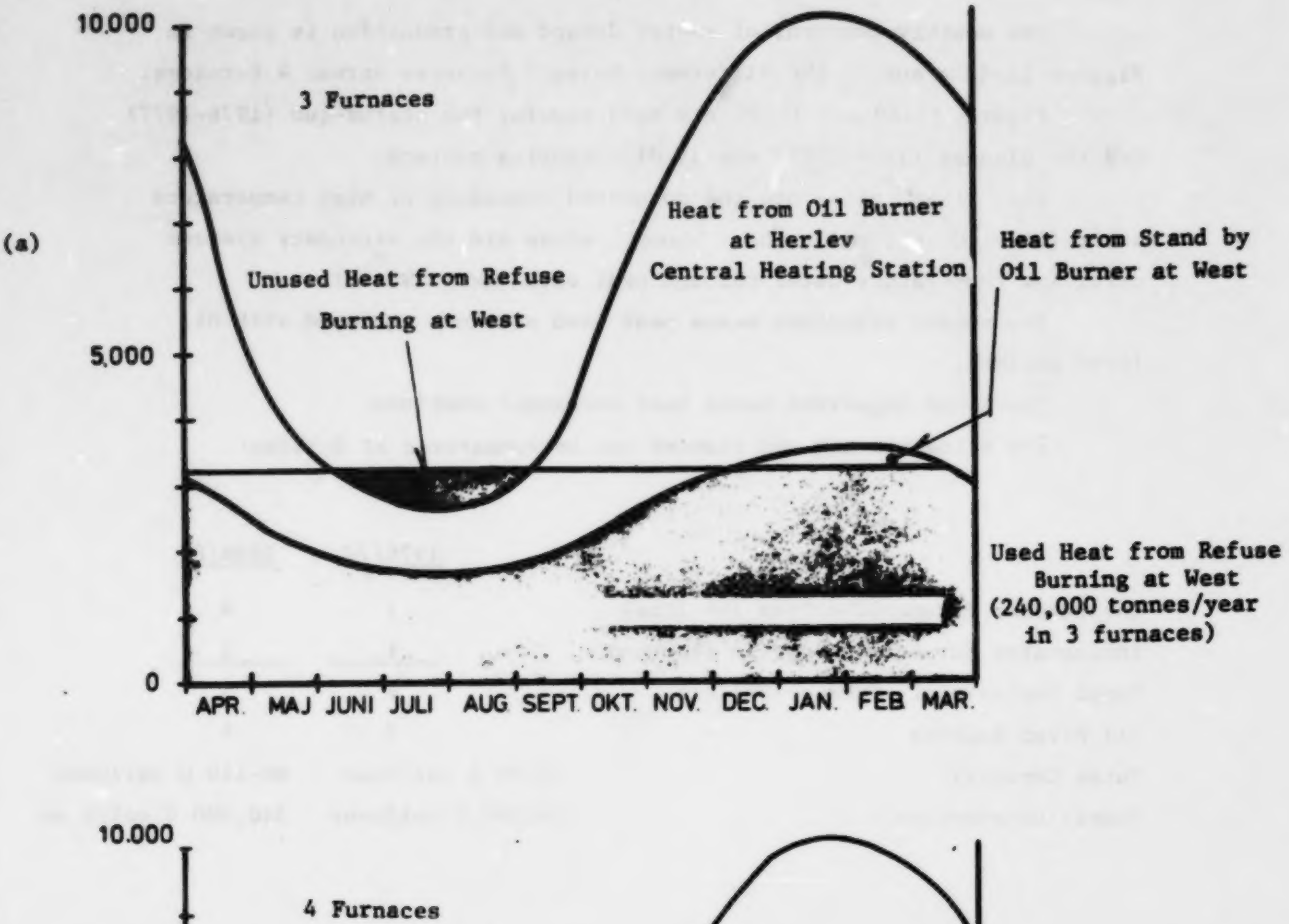
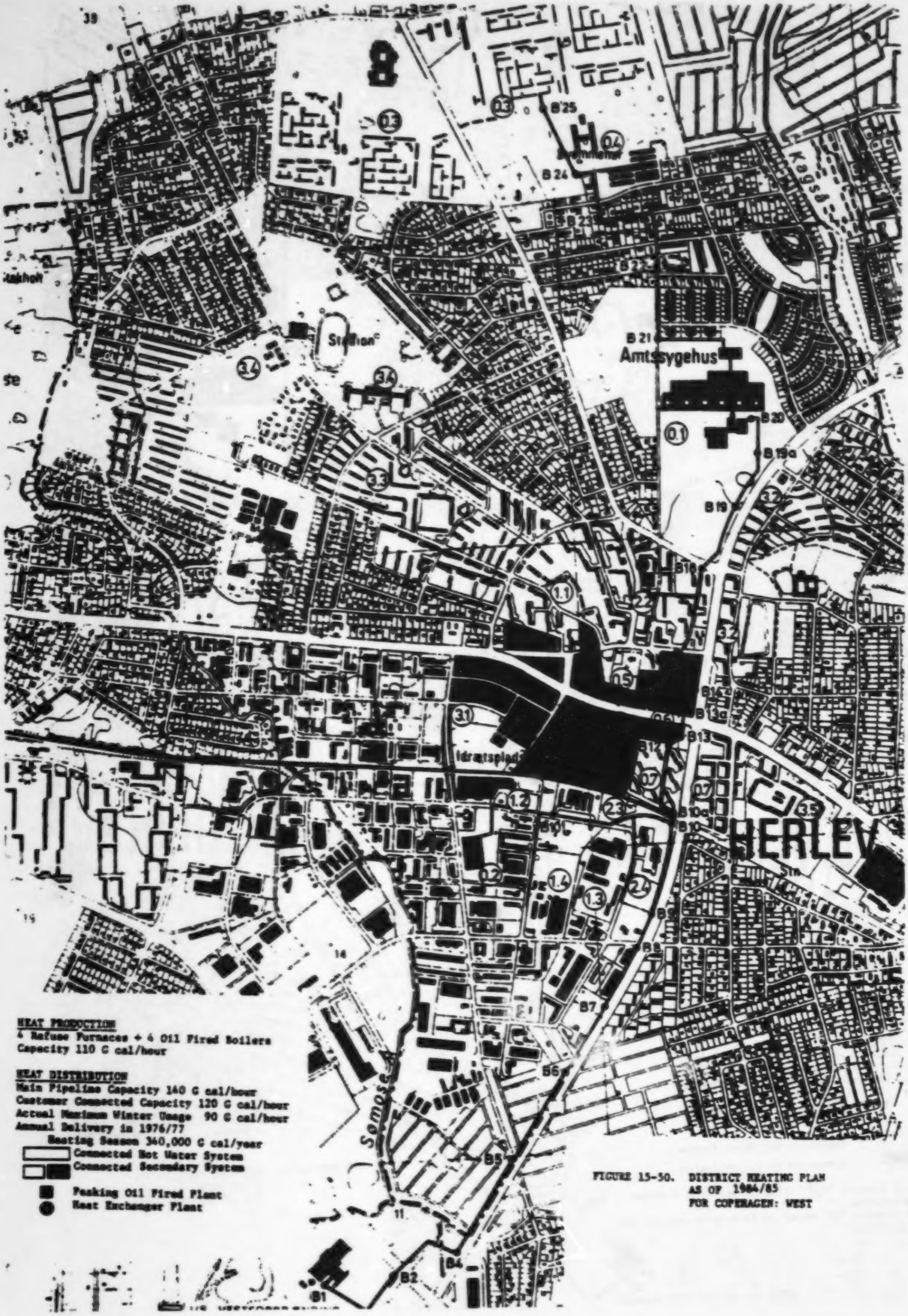


FIGURE 15-48. TONNES OF OIL PER MONTH OR EQUIVALENT ENERGY IN REFUSE


HEAT PRODUCTION
4 Refuse Furnaces + 4 Oil Fired Boilers
Capacity 110 G cal/hour
HEAT DISTRIBUTION
Main Pipeline Capacity 140 G cal/hour
Customer Connected Capacity 120 G cal/hour
Actual Maximum Winter Usage 90 G cal/hour
Annual Delivery in 1976/77
Heating Season 340,000 G cal/year
Connected Hot Water System
Connected Secondary System
Peaking Oil Fired Plant
Heat Exchanger Plant
Stadion
Amtssygehus
Idrætsplads
HERLEV
Kagså
Sømose
B1
B2
B4
B5
B6
B7
B8
B9
B10
B10a
B13
B19
B19a
B20
B21
B24
B25
01
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04
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12
13
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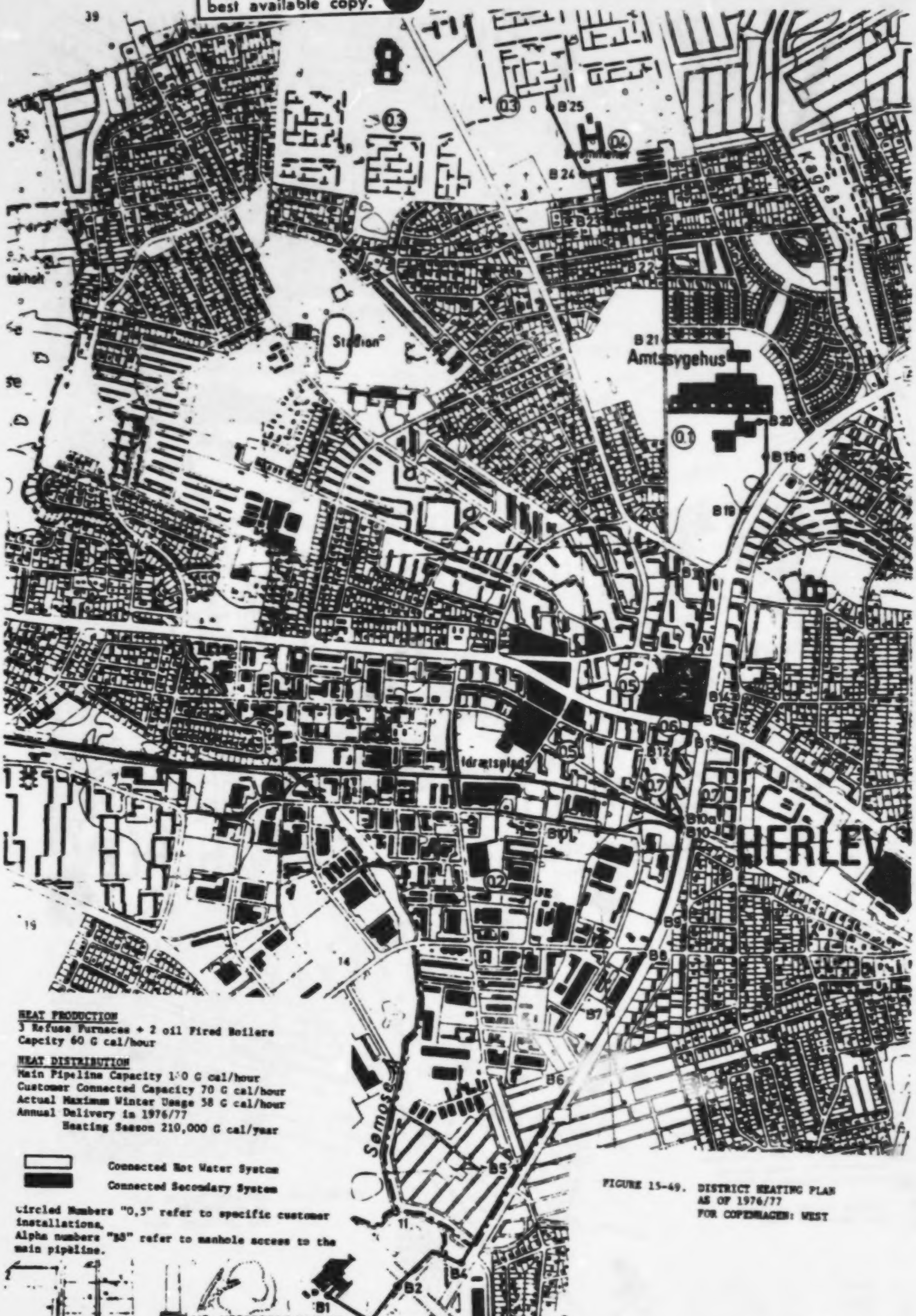
39

FIGURE 15-50. DISTRICT HEATING PLAN AS OF 1984/85 FOR COPENHAGEN: WEST

Reproduced from
best available copy.


39
03
03
B25
04
B24
B23
B22
Kagså
Stadion
B21
Amtssygehus
B20
01
B19a
B19
B18
05
B14
06
B13
05
B12
Idrætsplads
07
07
B10a
B10
B10b
HERLEV
02
19
B9
B8
14
B7
B6
Semose
B5
11
B4
B2
B1
I/S VESTFORBRÆNDING

HEAT PRODUCTION
3 Refuse Furnaces + 2 oil Fired Boilers
Capcity 60 G cal/hour

HEAT DISTRIBUTION
Main Pipeline Capacity 1'0 G cal/hour
Customer Connected Capacity 70 G cal/hour
Actual Maximum Winter Usage 58 G cal/hour
Annual Delivery in 1976/77
Heating Season 210,000 G cal/year

☐ Connected Hot Water System
■ Connected Secondary System

Circled Numbers "0,5" refer to specific customer installations,
Alpha numbers "B8" refer to manhole access to the main pipeline.

FIGURE 15-49. DISTRICT HEATING PLAN AS OF 1976/77 FOR COPENHAGEN: WEST

POLLUTION CONTROL EQUIPMENT

Both at Amager and West, Rothemeuhle two field electrostatic precipitators (ESP) are the sole means of air pollution control now in effect. Plant officials were hesitant about this and had thought of the need to add a mechanical cyclone collector after the ESP. They wanted to make sure that the larger paper particles would for certain be captured. Therefore, they mandated that room should be available for adding the cyclones later if necessary. The space is outlined with dash lines in the previous Figure 15- 2. As discussed later, there has been no need to add any cyclones.

The ESP inlet gas flow is 107,000 Nm^3/hour. The flue gas temperature is designed to be around 350 C (662 F). Volund estimates the maximum. Because of the clogging economizer section of the boiler, there have been many excursions well above 35 °C (662 F). Volund estimates the inlet loading to be 7.5 g/Nm^3.

Each of the two fields is a 8.5 m (28 feet) high and 7.0 m (23 feet) deep. Flow-model studies were conducted. The average flow velocity is 0.86 m/sec (2.8 feet/sec). The maximum is 1 m/sec (3.3 feet/sec). The flyash residence time in the ESP should be 1 to 2 seconds. The pressure drop through the ESP is 5 to 10 mm water (.2 to .4 inches water). Each ESP field has two rectifiers. Volund would permit a one-field ESP only on a small system where the regulations are not as stringent.

Even though the ESP is housed inside the normally warm furnace/boiler room, the ESP hoppers are equipped with electric heaters. When the room temperature falls to 10 C (50 F), the heaters prevent possible dew-point corrosion in the ESP.

Flyash is removed from the bottom of the EPS hoppers pneumatically as seen in Figure 15-51. Again returning to Figure 15-2, the pneumatic tube dumps onto a conveyor belt. The fly ash is transported to a steel silo which has a continuous discharge into a humidifier. From the humidifier the fly ash falls directly into the ash pit.

FIGURE 15-51. LOOKING OUT THE WINDOWS TAKEN FROM UNDER THE ELECTROSTATIC PRECIPITATORS AT COPENHAGEN: WEST

Flyash is not to be mixed with bottom ash so that the bottom ash can maintain its high pH and thus be recovered and used as "non-leaching" and "non-cementing" gravel. The fly ash falls into a corner of the silo and is not mixed with the clinkers.

The Danish regulation for particulates is 150 mg/Nm^3 corrected to 11 percent O_2 and 7 percent CO_2 (which are about the same). At West the so corrected reading was well within limits at 90 mg/Nm^3. The Danish Boiler Testing Company made the measurements. It was such an expected low actual reading that caused Rothemeuhlé not to put in the cyclone collector. However, if the reading were higher, Rothemeuhle (at its expense) would have had to install the cyclone.

Volund officials repeated a statement heard elsewhere in Europe and America that, "for each one percent above 96% efficiency, the ESP purchase price doubles". This of course is far from accurate. However, it makes the clear point that going from clean air emissions to very clean air emissions is very expensive.

They once tried to clean the ESP with water. Corrosion developed. They now use the dry method of compressed air.

ENVIROMENTAL AND ENER.Y CONSERVATION ASSESSMENT

Volund and West officials both referred to the air pollution and energy conservation impact of the waste-to-energy system as compared with the impact of burning the energy equivalent in tonnes of fuel oil in single family homes. The contents of sulphur in the waste are lower than 0.5 percent and emissions from the plant are under those found in a normal low percentage sulphur oil fired plant. Ambient ground level tests carried out in Copenhagen and surrounding areas did not show measurable traces of pollution from the two large refuse plants: West and Amager.

The refuse fired energy plant at West emits as much acid formers SO_2 and HCl, as do a combination of smaller furnaces burning fuel oil with 1 percent sulfur in the oil, i.e. 40,000 tonnes (44,000 tons) of oil. This happens to also be West's energy equivalent in oil. Similarly, controlling West's stack gas particulates to about 100 mg/Nm^3 results in an equivalent amount of emissions compared with burning 40,000 tonnes (44,000 tons) of oil without any home air pollution control.

Atmospheric dispersion is also a point in favor of using a central heating system instead of individual home or apartment furnaces. In Winter, the area is subject to air inversions. Having thousands of small chimneys 3 to 10 m (10 to 33 feet) is much less desirable than having one large 150 m (495 feet) stack. At this height dispersion out of the country is a substantial plus--for Denmark.

With respect to lead (Pb), West produces an amount equivalent to 200 cars. But the refuse generation shed of the West plant has a population of 650,000 people and about 300,000 cars. Thus the population's automobiles produce 1,500 times as much lead than does the West plant.

Water pollution of landfill refuse leachate is also an environmental issue. All other considerations set aside, if refuse is used for district heating, then this raw refuse will not be landfilled. Refuse burning destroys most harmful organics.

Figure 15-52 shows refuse volume reduction as a function of various solid waste treatment and disposal methods. It appears that the excellent burnout rate in the Voland rotary kilm followed by thorough ash reclamation result in volume and weight reductions of more than 95%. In 1975, West consumed 255,000 tonnes of refuse, produced 60,000 tonnes of processed ash for sale and landfilled 10,000 tonnes of unrecliamable material.

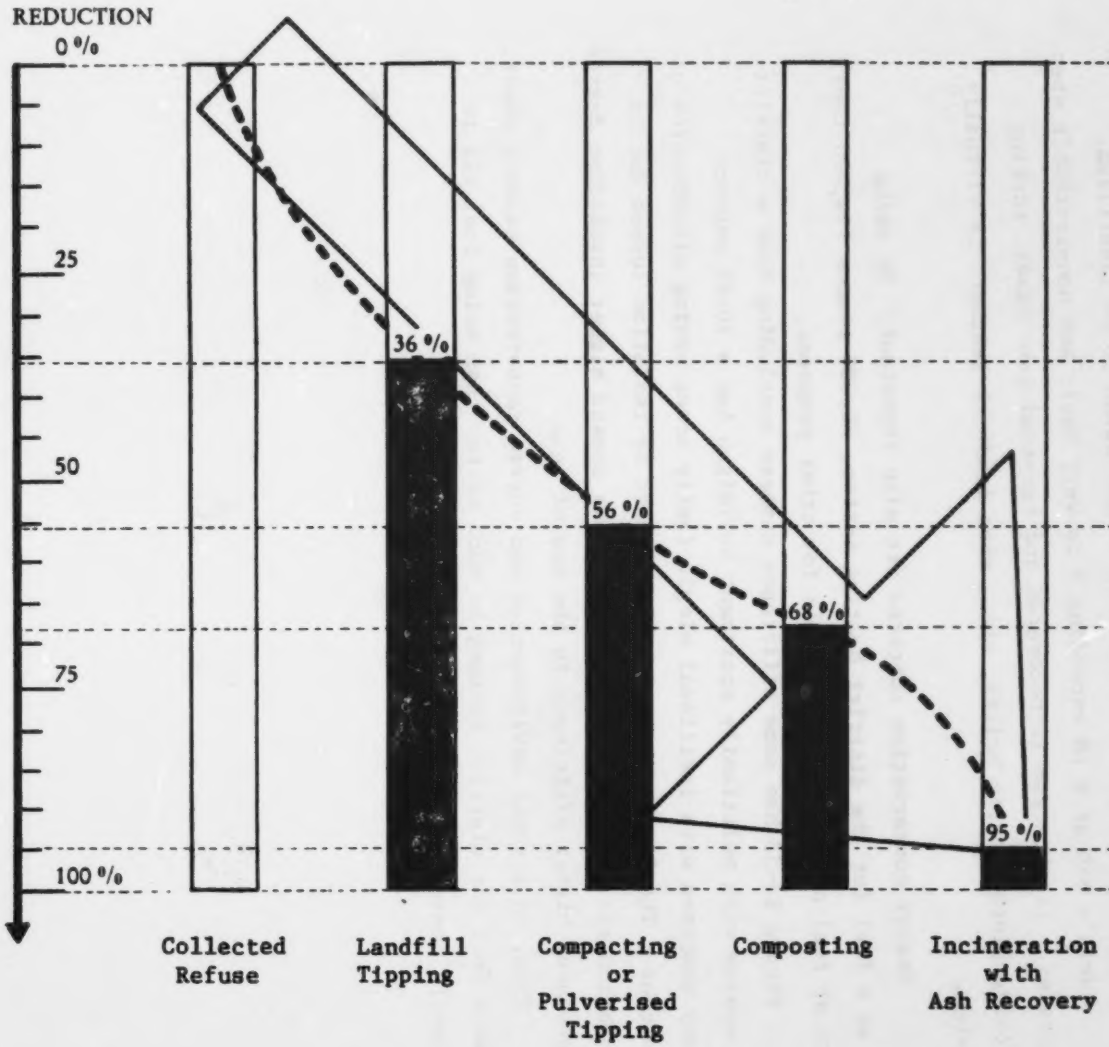


FIGURE 15-52. REFUSE VOLUME REDUCTION AS A FUNCTION OF VARIOUS TREATMENT METHODS

Thus, only 4% by weight of the input refuse had to be landfilled. This means that only 1 or 2% of the refuse by volume needs to be landfilled.

West's ash at a pH exceeding 9 is very basic and non-leachable when concentrated. If this ash is recovered and recycled into roads, parking lots, cinderblocks, patio bricks, etc., then landfill leachate is virtually eliminated.

Energy conservation concerns are also important. By using refuse as a fuel for the district heating system, 40,000 tonnes (44,000 tons) per year of fuel oil are then available for other purposes.

Figure 15-53 has some efficiency numbers concluding that a district heating system with multifamily apartment buildigns has a 70-85 percent efficiency compared with indifidual single family homes having efficiencies of 50-60 percent. The losses shown are also caused by radiation losses due to bad insulation etc. Today modern building laws demand higher insulation degree with consequent higher efficiency in the use of heat.

Thus, on a total environmental and energy conservation balance sheet, refuse as a fuel for district heating is much better than using fuel oil in single family homes.

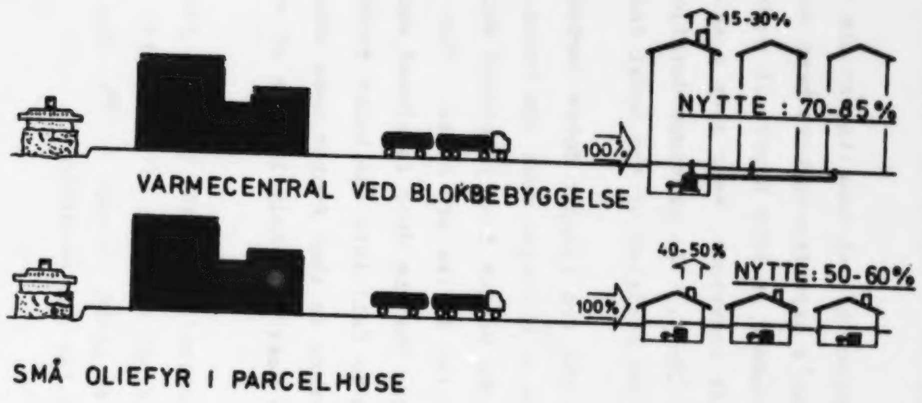

15-30%
NYTTE : 70-85%
100%
VARMECENTRAL VED BLOKBEBYGGELSE
40-50%
NYTTE: 50-60%
100%
SMÅ OLIEFYR I PARCELHUSE

FIGURE 15-53. SCHEMATIC SHOWING HOW A CENTRAL DISTRICT HEATING APARTMENT SYSTEM COMPARES IN EFFICIENCY WITH INDIVIDUAL HOME HEATING SYSTEMS

ASH HANDLING AND PROCESSING

The subject of "ash" is discussed in two major sections of this report. This section on Ash Handling and Processing discusses matters at the West plant itself. The later section on Ash Recovery discusses physical and chemical properties of processed ash as a usable gravel material. This following section also discusses the encouraging environmental story of ash percolate (leachate).

Returning to the subject of ash handling at the West plant, mention should be made that West's experiences have been much better than those of Amager - as fully discussed in Trip Report 14 - Amager. In contrast to Amager's rubber belt conveyors, West uses a skip hoist as shown in the dump position in Figure 15-54. The previous detailed cross sectional view (see Figure 15-2) shows the position of the hoist rails.

Also to be noted are the two flapper doors (swivel gates) that control in-plant ash atmospheres to minimize dust and noise. When the hoist is traveling or dumping, the bottom door is closed while the top door is open. Ash thus accumulates in the ash chute. When the hoist returns and the chute has filled, the top door is closed and the bottom door is opened to allow the ash to fall into the hoist bucket.

Another major difference is that Amager uses about 3 tonnes of water per tonne of ash while West uses only 1 tonne of water per tonne of ash.

Figure 15-55 is a diagram of the ash recovery plant. The ash leaves the building and goes through a series of vibrators, sieves, magnets and conveyors as shown in Figures 15-56 through 15-59. The ash less than 45 mm (1.8 inches) is stored on the ash mountain.

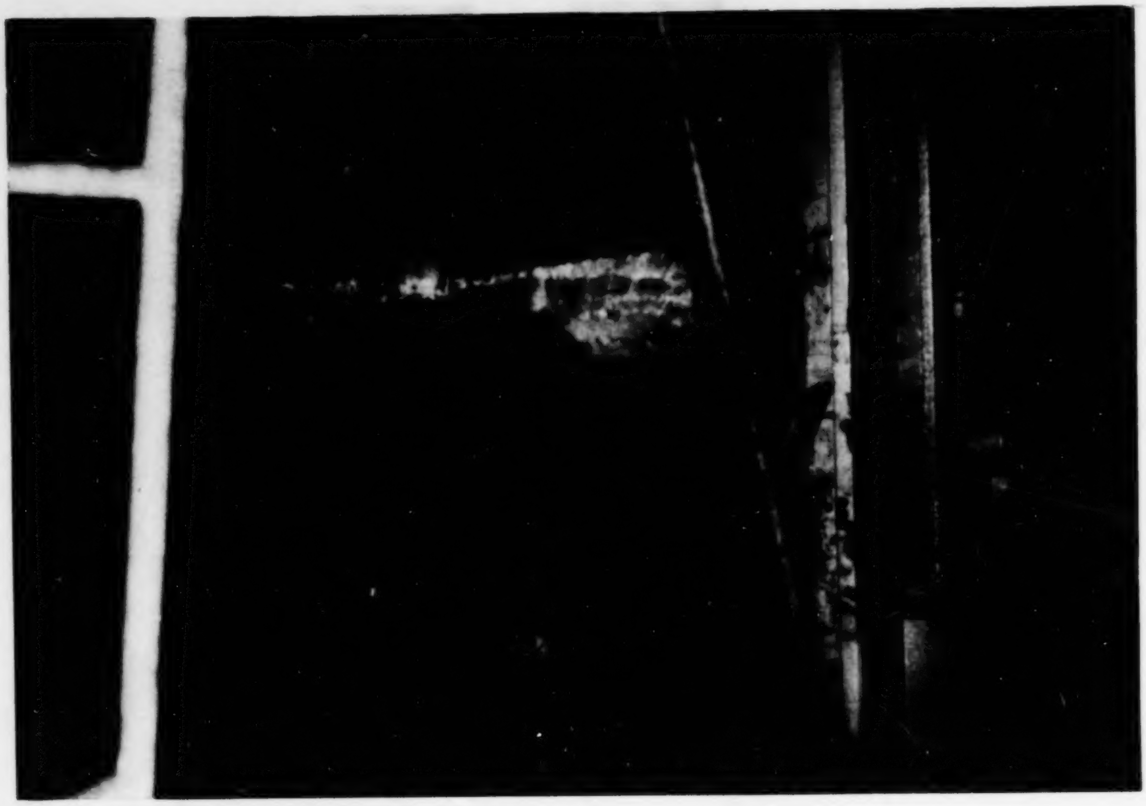


FIGURE 15-54. SKIP HOIST DUMPING INCINERATOR ASH (SLAG) AT COPENHAGEN: WEST

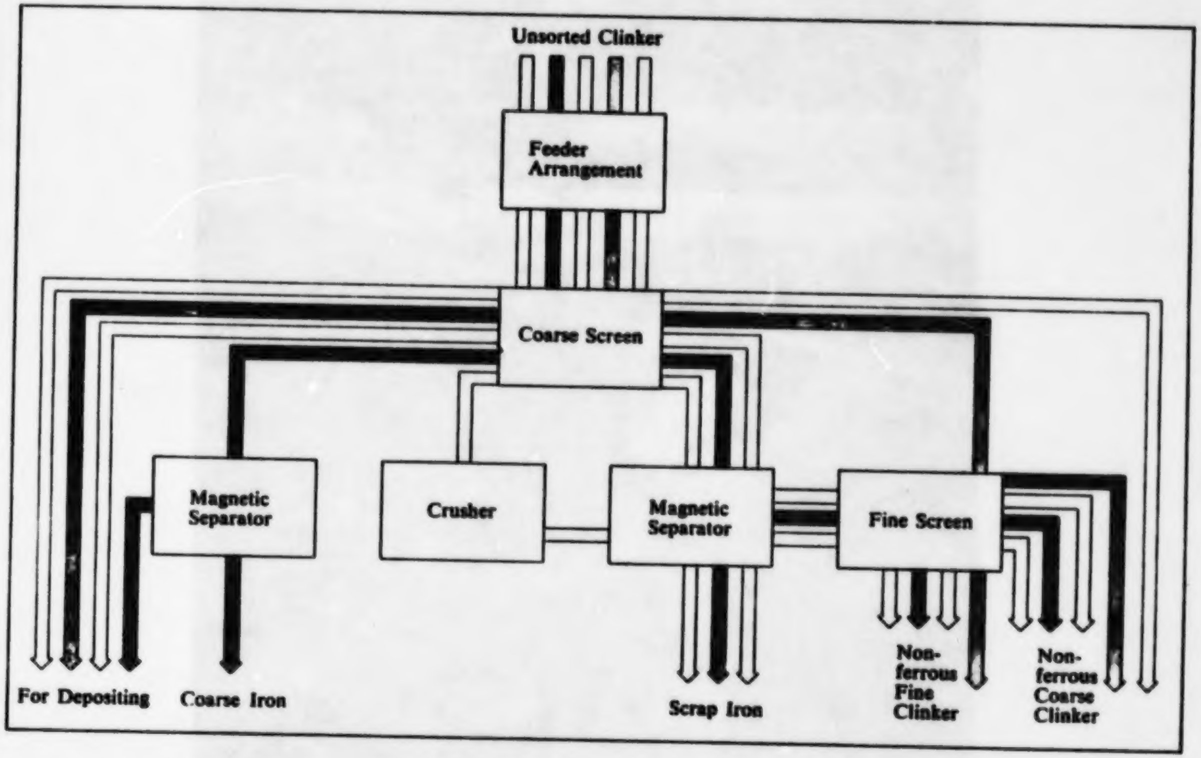

Unsorted Clinker
Feeder Arrangement
Coarse Screen
Magnetic Separator
Crusher
Magnetic Separator
Fine Screen
For Depositing
Coarse Iron
Scrap Iron
Non-ferrous Fine Clinker
Non-ferrous Coarse Clinker

FIGURE 15-55. ASH HANDLING AND PROCESSING AT COPENHAGEN: WEST

FIGURE 15-56. ASH RECOVERY AT COPENHAGEN: WEST

Cinder Blocks
made from
Reclaimed Ash

FIGURE 15-57. VIBRATING MACHINERY FOR ASH PROCESSING AT COPENHAGEN: WEST

FIGURE 15-59. MOUNTAIN OF PROCESSED ASH RESIDUE AWAITING USE FOR ROADBUILDING OR CINDER BLOCK MANUFACTURE AT COPENHAGEN: WEST

ASH RECOVERY

Background

Ash recovery at Copenhagen: West is very advanced. It was the subject of a 42 page report (English version available) co-authored by the Danish Geotechnical Institute (DGI) and the Water Quality Institute (WQI) entitled, "Cinders and Reuse." Sections of the report were written by Mr. T. Balstrup (DGI) and by Mr. Sven Dige Pedersen (WQI). The report is divided into two sections. The Geotechnical Qualities of Cinders and Environmental Aspects Surrounding Combustion Cinders. Key paragraphs have been repeated where it would benefit this trip report.

Back in the early 1970's, when Copenhagen: West was conceived, the only clear alternative was to place cinders in a landfill with plastic liners and a leachate collection system. Even by 1972 useable research results were not available or known. In fact, in Denmark, research had not even been started in this area.

Both institutions performed their work between 1972 and 1975. While research was being conducted, the plant continued to place unprocessed ash in the Vestskoven landfill.

The research proved interesting and successful in the following applications:

Application 1.	Base and foundation for small and lightly traveled local roads
Application 2.	Bicycle paths
Application 3.	Parking lots
Application 4.	Below floor building construction
Application 5.	Foundations carrying light loads

The following are numbers reflecting the normal annual operation:

Quantities

	Tonnes
Quantity of waste combusted	240,000 to 300,000
Quantity of raw ash or crude cinders	50,000 to 75,000

Quantity of usable gravel cinders	40,000 to 60,000
Quantity of reusable ferrous *	4,000 to 6,000

	*Ferrous Distribution
Caps and capsuls	20.8%
Identifiable tin cans	10.9%
Metal strips, spoons, and scissors	10.4%
Nails and screws	11.5%
Scrap metal - big pieces	17.7%
Scrap metal - small pieces	28.7%

Flyash

Flyash is excluded from the research because supposedly its cement-like properties and low pH would interfere with the gravel-like applications. Flyash at Copenhagen: West is separately collected in a corner of the clinker silo and separately disposed.

Road Test Procedures

In order to establish a basis for initial evaluation and future control, it was decided by DGI to employ the same test procedures for the classification of the cinders as those used within road building for the evaluation of sand and gravel materials. This was done with the full knowledge that they were dealing with a product of another grain structure, and without systematical experiences from full-scale plants.

Laboratory tests included determination of grain density, ignition loss, grain distribution analyses (Figure 15-60), density determinations by dry embedment and by Proctor tests, CBR tests, permeability- and capillary tests, and finally determination of strength and deformation characteristics by triaxial compression- and consolidation tests. Technical

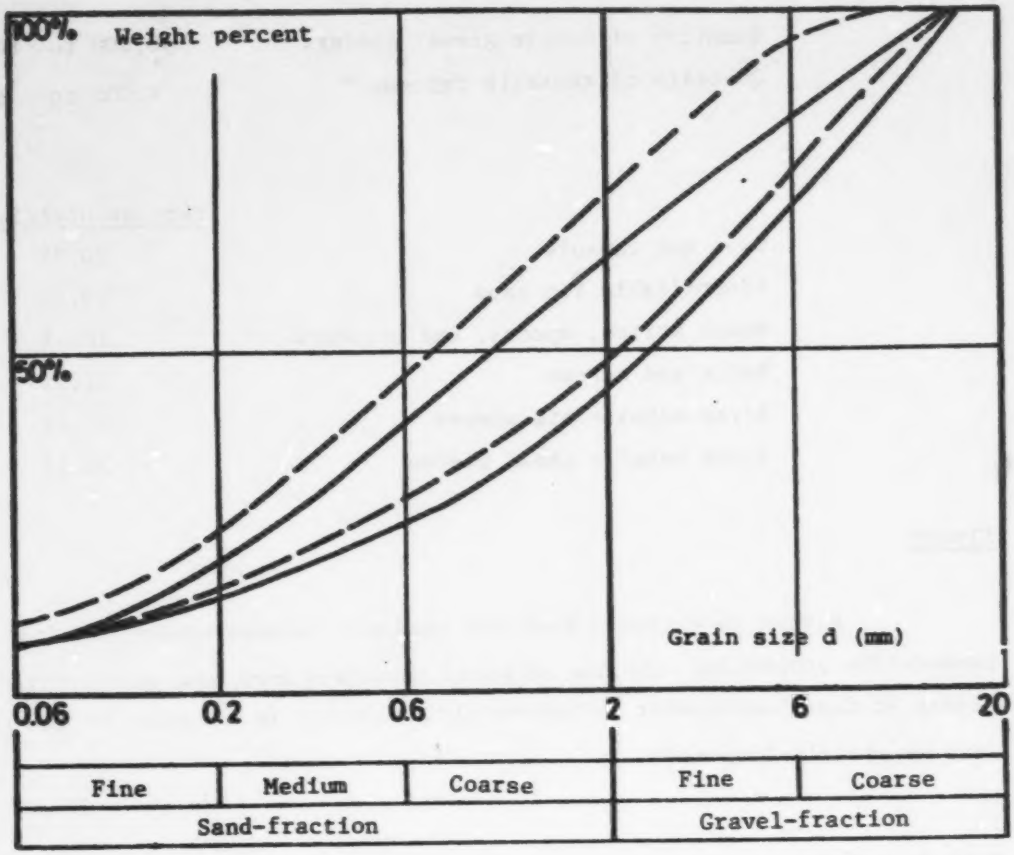


FIGURE 15-60. **The variation interval for the 16 mm fraction of graded cinders before (solid line) and after (dotted line) compacting by field tests.**

results are presented in the report. Furthermore, examinations have been made of crushing of grains of the cinders material by means of pounding processes, and the deformation of the built-in cinders due to repeated loads.

At the conclusion of the combustion process the cinders are cooled down by watering. They subsequently have a moisture content near 20 percent which corresponds to the maximum quantity for building. Tests were carried out in a very rainy and cold period which did not change the moisture content of the cinders, as a satisfactory drainage through the cinders to the surrounding area took place.

After sorting over a 45 mm (1.8 inch) screen which mainly retains tin and large pieces of iron, the cinders appear as a homogenous material. It is so aesthetic that it does not resemble a waste product, and it can be used in populated areas without problems. The sorted out large material comprises only about 5 percent of the total cinders. In 1977, the process had matured so that now 20 percent of the total cinders is removed for ferrous recycling, reburning or direct landfilling. The cinders do not cause any special dust- or smell nuisances.

The main results from the test field show that for the graded cinders a homogenous compacting is obtained which improves gradually with the number of roller passages. On account of the good strength quality of the cinders, the compacting depth is limited. However, there is improvement when vibration equipment is used. By compacting to optimum density, a crushing of the grains of the cinders occurs. The drained layer of cinders will retain its optimum moisture content even during periods with plentiful precipitation.

Laboratory tests furthermore demonstrate that a cementat
occurs, which in the course of three to four weeks will increase th
and deformation qualities of the cinders by primary loads by 50 to

Parking Lot and Road Test Results

A 15,000 m^2 (161,400 ft^2) parking lot was covered with 60 x 60 x 8 cm (2 x 2 x .3 feet) concrete slabs. Underneath, at least 40 cm (16 inches) graded cinders with a 5 cm (2 inches) screen of gravel have been used. The cinders were laid out loosely in up to 40 cm (16 inches) thickness and compacted. After almost one year's use, only significant settlings ($<$ 1 cm) (less than 0.4 inch) have been registered.

For a temporary road approach system with relatively heavy traffic in Herlev municipality, the graded cinders have partly been used as foundation and base. The construction work shows that the compacted cinders without asphalt surface could carry the traffic without appreciable problems during the work period, even during a spell with plentiful precipitation, and that the compacted cinders by the successive replacement of the wet and mushy deposits could stand with an almost vertical slope two to three meters tall. Settling and tracking tendencies will be followed for the finished construction.

This road section of approximately 120 m (400 feet) is made from 7 cm (2.8 inches) gravel asphalt concrete, 13 cm (5.1 inches) stable gravel and 28 to 38 cm (11 to 15 inches) graded cinders. After completion of the road construction height surveys at 16 points of the road surface have been carried out in the period January 1976 to February 1977. The measurements indicate settlings of 0 - 5 mm. While the main part of the points with 28 to 38 mm indicate 5 - 10 mm frost heave in the period February - March 1976, the point which had been replaced with approximately 2 meters cinders the frost heave is $<$ 5 mm. The original soil base consists of medium solid marine clay.

Finally, cinders have been used for foundations and base of local roads and parking lots for a school in Ballerup. The foundation and base of cinders was directly used as workroad during a period with precipitation and changing thaw and frost. Apart from local softening of the uppermost centimeter of cinders, no significant impediments for the work traffic were registered. The moisture content of the cinders under the softened zone correspond to the optimum level. Observations from these construction jobs so far seem to validate the use of cinders for road construction purposes.

Environmental Tests - General

Since the autumn of 1971, the Water Quality Institute (WQI) have carried out a series of tests for Copenhagen: West of the environmental aspects by depositing and use of combustion cinders. The following tests have been made:

- Accelerated washing out tests on laboratory scale.
- Tests of the washing out process form a non-covered cinders depot.
- Tests for characterization of graded cinders.
- Tests of the washing out process from a parking lot, where graded cinders are used as foundation material.

Environmental Test Results - General

A most interesting and positive test result is caused by the pH of the cinders being around pH 9-11. The strong alkaline presence in bottom ash is due to the high concentration of carbonate. The favorable aspect is that in this pH range, most of the heavy metals are thermodynamically stable. Thus fewer of the heavy metals will dissolve into ground water solution for eventual entrance into the drinking water systems. The next several paragraphs by Mr. Pedersen explain the environmental chemistry in greater detail.

Liquid Percolate (leachate), Fresh Water, Sea Water, and Drinking Water

Tests and Results - Unprocessed Cinders At Special Sanitary Landfill

The depositing of cinders was done in "depots", shaped like big hollows with the under-side two to three meters below ground. The dug out earth is put up like a circular wall, so that the hollows are four to five meters deep. On the inside, the hollows are lined with a heavy, coherent plastic diaphragm in order to prevent penetration of the percolate to the groundwater. The percolate runs to a centrally located pump well, from which it can be picked up and analysed.

The object was to shed a light on the washing out process from an uncovered cinders depot, and to establish if there are traces of percolate in groundwater borings around the depositing site. Tests of secondary groundwater and percolate of cinders from the locality in Vestskoven where the cinders are deposited, were taken in the period from June 1973 to October 1975.

No measurings or analyses of groundwater samples have evidenced any adverse influence from the percolate of cinders in this period.

The concentration of macro ions (e.g. calcium, sodium, sulphate and chloride) in the percolate is of the same size as the concentrations in sea water.

Among the examined trace elements, hereunder also heavy metals, only the concentrations of arsenic are bigger than the concentration in the groundwater samples in the test period from June 1973 to March 1974. However, it is substantially smaller than the drinking water criterion for arsenic.

The concentration level for trace elements has not changed essentially in the period 1974/75. In Table 15-5 analytical values of trace elements in the percolate are compared with the values for river water, sea water, as well as various drinking water criterions.

TABLE 15-5. ANALYTICAL VALUES OF TRACE ELEMENTS IN THE PERCOLATE

Analysis variable	Percolate 1973-74 min.	Percolate 1973-74 max.	Percolate 1974-75 min.	Percolate 1974-75 max.	Fresh-water median	Sea water	Drinking water criterions WHO	Drinking water criterions Sweden	Drinking water criterions USA	Drinking water criterions USA
Al	<1	1080	2,5	108	240	10		150		
As	4,5	16,5	10,6	20,5	0,4	3	50	200	50	100
Pb	2	<10	2	12	5	0,03	100	100	50	50
Cd	<0,1	<20	<1	<10	<80	0,1	10	50	10	10
Cr(tot)	10	<50	<5	80	0,2	0,05				50
Fe	7	370	<100	300	670	10	300	200	300	300
Cu	<1	80	<1	24	10	3	1000	50	1000	1000
Hg	<0,05	0,29	<0,05	0,25	0,08	0,03				2
Mn	29	300	30	50	12	2	100		50	50
Zn	10	150	25	60	10	10	5000	1000	5000	5000
B			<250	560	13	4600				(1000)
Se			2		<20	0,09	10	50		10
Ni			<50		10	5				-
Co			<50		0,9	0,3				-
Ag			40		0,1	0,3		50		-

Measured minimum and maximum concentrations of trace elements in percolate in the period June 1973 to March 1974, as well as March 1974 to October 1975, compared with the values for fresh water, sea water, as well as different drinking water criterions. All values are shown in ug/l.

The main cause of the low concentrations of trace elements in the percolate is the high pH value (∼ 10) of the cinders which gives the percolate a pH value of approximately 9. At this pH level all examined trace elements are thermo-dynamically stable in a solid form. The trace elements are either immune (non-corrosive) or passive (coated with a dense skin of the corrosive product which prevents further corrosion) to attacks of water. The redox (reduction-oxidation) conditions in the depot (greatly reducing with hydrogen sulphide development) increases this tendency further, as possible dissolved trace elements from the top side of the depot will be tied up as very sparingly soluble sulphide deeper down in the depot. The presence of complexing ions (NH_4^+, Cl^-, HCO_3^-) will only to a lesser extent be able to increase the solubility.

No higher solubility of trace elements than the one observed up till now can be expected, as long as the present pH- and redox conditions are maintained in the cinders. A noticeable change will first occur if the pH value of the cinders falls to pH 7 or lower. Such a change can only be caused by a neutralization of the alkaline parts of the cinders with acidic precipitation. The following calculation shows the length of time such a neutralization will require:

Alkalinity of the cinders: 0.975 equiv./kg
Acidity of rain water: 10^{-4} equiv./l (pH 4)
Quantity of cinders in depot 1: 15.600 tons
Quantity of percolate per year: 452 m^3
"Neutralization time": $\frac{15,600 \times 0.975}{452 \times 10^{-4}}$ years = 336,500 years

By the washing out from the depot some of the alkaline parts of the cinders are removed. This means that a neutralization of depot 1 would last less than the period indicated, but still a very long time (thousands of years).

Solid Processed Cinder and Soil Comparative Tests

By comparison with soil analyses, it can be seen (Table 15-6) that the following elements in the cinders are present in a concentration which is greater than the upper limit of the range of distribution for concentrations in cultivated soil:

Cadmium
Chloride
Copper
Sodium
Lead
Sulphur (sulphate)
Zinc

Sodium and chloride mainly originate from wood and kitchen refuse (food scraps). A small part of the chloride may have been produced by the combustion of PVC which is present in the garbage in minute quantities. Sulphate is presumed to originate mainly from cardboard and paper waste. Zinc and cadmium are present in the ratio 460:1 which means that the main part of cadmium in the cinders has its origin as metal residues (pollution) in the zinc (normal ratio 100:1 - 1000:1). The zinc is added from a great number of sources. Copper presumably comes mainly from electrical wire, and to a certain extent from copper-plated metal objects. Lead is presumed mainly to originate from food tins, paint, and painted articles which are dyed with lead pigment, as well as lead batteries.

The high pH value of the cinders, pH = 10.1, fixes the trace elements so that no significant quantities will be washed away from the cinders materials. In slightly acid surroundings, which may be found if cinders are spread and plowed down, the quantity of elements accessible for assimilation in plants will increase as the pH is lowered.

Test on Parking Lot in Ballerup

In the autumn of 1974, I/S Vestforbranding received permission to lay out a 40 cm deep layer of cinders as foundation of the parking area near Ballerup's town hall.

TABLE 15-6. ELEMENT COMPOSITION OF SOIL AND CINDERS (ALL ANALYSES ARE MADE ON DRY MATERIAL)

Analysis variable	Unit	Soil variation width /12/	Soil average /12/	Cinders average
Nitrogen	g/kg	0.2 - 2.5	1.0	0.66
Phosphorus	g/kg		0.65	2.71
Carbon	g/kg		20	12++)
Chloride	g/kg		0.1	81.5
Sulphate	g/kg	0.09 - 2.7+)	2.1+)	10
Calcium	g/kg	7 - 500	13.7	32.2
Sodium	g/kg	0.75 - 7.5	6.3	7.6
Magnesium	g/kg	0.6 - 6	5	2.6
Potassium	g/kg	0.4 - 30	14	3.2
Aluminium	g/kg	10 - 300	71	21
Arsenic	mg/kg	0.1 - 40	6	8.8
Lead	g/kg	0.002 - 0.2	0.01	1.56
Boron	mg/kg	2 - 100	10	<0.25
Cadmium	mg/kg	0.01 - 0.7	0.06	5.0
Chromium	mg/kg	5 - 3000	100	45
Iron	g/kg	7 - 550	38	28
Copper	g/kg	0.002 - 0.1	0.02	2.8
Cobalt	mg/kg	1 - 40	8	8.7
Mercury	mg/kg	0.01 - 0.3	0.03	0.13
Manganese	g/kg	0.1 - 4	0.85	0.88
Nickel	mg/kg	10 - 1000	40	73
Silver	mg/kg	(0.01 - 5)	(0.1)	4.6
Zinc	g/kg	0.01 - 0.3	0.05	2.3

+) : Converted from sulphur.

++) : Converted from carbonate.

The Danish Environmental Protection Agency and Copenhagen's water supply plant wanted tests to be made of the drainage from the area. When the parking lot was built, a diaphragm was put under part of the cinders foundation, so that there was direct drainage from the lower side of the cinders material to a collecting well. Furthermore, the whole area is drained, so that it is possible to collect drain water which has passed through the layer of gravel under the cinders.

Table 15-7 shows the results of tests of percolate, drain water, and water running off the surface of the parking area. The percolate from the cinders layer (sorted cinders) has the character of diluted percolate from the depot in Vestskoven, as it has been diluted four to eight times. The concentration of the trace elements lead, cadmium, copper, and zinc is of the same magnitude as in the percolate from the Vestskoven depot, while the concentration of chromium is smaller.

During the passage through approximately 1 m concrete, gravel and the drain pipes, the percolate is oxidized, the ion strength is reduced, and the main part of the nitrogen is absorbed by the gravel.

The concentration in the drain water of the trace elements lead, cadmium, chromium, and copper is less than or equal to that in the percolate before passage through the gravel layer, while the concentration of zinc is somewhat greater.

Water running off the surface had a lower chloride content that the drain water. The concentrations of trace elements in water running off the surface is bigger for lead (8 to 16 times), copper (1.5 to 3 times), and zinc (2 to 6 times), while it is of the same low size for cadmium and chromium.

During a situation in September 1975 with 21 mm of precipitation, the quantity of precipitation was removed from the area in the following way:

Evaporation:	41%
Surface run-off:	36%
Drainage:	23%

It has been calculated that with the use of a drain water quantity of 23 percent per year per m^2, a quantity of chloride is washed away from

TABLE 15-7. COMPARISON OF ANALYSES OF PERCOLATE FROM DEPOT 1 IN VESTSKOVEN AND PERCOLATE, DRAIN WATER, AND SURFACE RUN-OFF FROM PARKING LOT IN BALLERUP

Analysis variable	Unit	Percolate Vestskoven	Percolate Ballerup		Drain water in Ballerup				Surface run-off Ballerup July
			April	October	April	July	July	Sept.	
pH		9.8		8.6	7.8	6.6- 7.1	6.5	8.2	7.2
Conductive power	mmho	21.4	6.20	3.27	2.10	3.03	3.23	1.91	1.19
Chloride	g/l	8.40	2.20	1.01	0.85	0.91	0.98	0.49	0.27
Dry matter	g/l	19.2	4.81		1.75				
Ignition loss	g/l		0.35		0.01				
Chemical oxygen comb.	mg O_2/l	36		26		10.4	12.4	3.9	10.4
Total nitrogen	mg N/l	23.6		21.0		2.7	4.7	2.0	1.9
NH_3 nitrogen	mg N/l	23.5	15.0	18.6	0.85			1.9	
Total phosphorus	mg P/l	0.17		0.20		0.012	0.12	0.017	0.032
Sulphide	mg s^{--}l	11-102	3,12		0,04				
Lead	µg/l	12	<10	14	<10	<5	<5	10	79
Cadmium	µg/l	<5		<5		<5	<5	<5	<5
Chromium	µg/l	40		<5		<5	<5	<5	<5
Copper	µg/l	24		30		8	6	11	17
Zinc	µg/l	25	<10	20	<10	67	50	20	120

the cinders which corresponds to the quantity of chloride which is added per m^2 roadway/parking lot when there are five to nine applications of road salt during the winter season. The washed out quantity of chloride per year will decrease gradually as the present chloride in the cinders is washed away. During the winter of 1973/74 there were 35 applications in Copenhagen, and on some of these occasions, salt was distributed twice, corresponding to about 50 applications.

Furthermore, similar calculations show that the yearly washed out quantities of the trace elements lead, cadmium, chromium, copper, and zinc with the drain water from the area is smaller than the quantities which are added to the area yearly through precipitation from the atmosphere.

The calculations show that a very long period of time will elapse (thousands of years) before the alkaline parts of the cinders have been neutralized by acid precipitation.

The washed out quantities of substance with the drain water from the newly built parking lot will expectedly decline gradually as the area is consolidated and the joints between the flagstones become compact, so that the part of the precipitation which runs off the surface will constitute an increasing share, while the part of the precipitation which is removed from the area through drainage will constitute a decreasing share.

By using a dense surface dressing, such as asphalt and concrete, the washed out quantities of substance from the cinders, other things being equal, will be quite insignificant, as the quantity of drain water which is a presupposition for a wash-out of the cinders will be extremely modest.

Cinders as Excellent Landfill Cover Material

An alternative possible application for the cinders is the concentrated use of them to cover dumping grounds. Here the alkaline percolate from the cinders will help to reduce acid conditions in part of the dumping ground, so that the total washing out of trace elements from the dumping ground is reduced. However, the washing out of trace elements from the cinders themselves will increase as the pH is reduced.

NOTE: To repeat, much of the above was borrowed from this excellent report by Msrs. Balstrup and Pedersen.
[We request that Mr. Pinto obtain permission from these two authors for us to repeat their materials. Perhaps they could help us condense the material to 10 pages]

CHIMNEY

The chimney was constructed by a local contractor, Ramboll Hannemann, using a Polish patented system for continuously pouring concrete. The stack has a 2.8 m (9.2 ft) diameter. Most of the stack is lined with 280 mm thick plain carbon steel. The flue gas velocity is 27 m (89 ft) per sec. At the top 10 m (33 ft), there is a corten steel core liner that is used to prevent corrosion. It is an antiacid steel.

The stack height is 150 m (495 ft). Volund had recommended only 100 m (330 ft). However, a local citizens group concerned about wintertime air inversions prevailed at the 150 m height.

COMMENT: Interestingly, some citizen groups at other locations develop equally strong favorable feelings about a short chimney that no one can see.

ORGANIZATION, PERSONNEL AND TRAINING

Organization

The West Incinerator partnership is made up of the following municipalities:-

	Refuse Tonnes 1972/73	Inhabitants	General Assembly Council Members	Management Members
Ballerup	13,900	51,400	6	1
Birkerød	5,900	21,400	3	1
Farum	3,000	13,600	2	1
Gentofte	24,900	73,700	6	1
Gladsaxe	28,900	71,100	6	1
Glostrup	8,400	22,000	3	1
Herlev	6,400	24,700	3	1
Ledøje-Smørum	1,000	6,300	2	1
Lyngby-Taarbaek	17,700	57,800	6	1
Vaerløse	4,300	16,100	3	1
Rødovre	11,000	42,000	5	1
Copenhagen	52,600	185,000	7	1
Subtotal	178,000	585,100	35	12
Hillerod (Transfer Station)	6,600			
Other Industry, Institutions	33,800			
Total	221,400			

The partnership is a "joint municipal company which can be joined by customers and other municipalities for a term of years.

The top authority of the company is the General Assembly (The Council), to which the participating municipalities are entitled to elect a number of members in accordance with the regulations and in relation to the size of the municipalities. (See Figure 15-61).

Members of West General Assembly and Board of Directors Chosen for the Period of April 1, 1974 to March 31, 1978

BALLERUP KOMMUNE
Borgmester, cand. jur. Kaj H. Burchardt,
formand for bestyrelsen
Chauffør Helge Hansen
Postvagtmester Skjold Jacobsen
TV-tekniker Arne Maischnack
Skatterådsformand Gudrun Petersen
Fabrikant Knud Pedersen
Typograf Knud Ø. Rasmussen

BIRKERØD KOMMUNE
Trafikkontrollør Poul E. Frederiksen
Byrådsmedlem Birthe Larsen
Major H. Søndergaard-Nielsen
Byrådsmedlem Hans Rasmussen,
bestyrelsesmedlem

FARUM KOMMUNE
Sognepræst T. Gudmand-Høyer
Politiassistent Villy Hansen, best.medlem
Adjunkt Eva Møller

GENTOFTE KOMMUNE
Skoleinspektør Erik Gruno
Viceskattedirektør Bent Kristensen
Fuldmægtig, cand. jur. Birthe Philip
Kommunalbestyrelsesmedlem Inge Skafte
Husholdningskonsulent Ellis Tardini
Vicedirektør Steen Vedel, best.medlem
Adm. direktør Bjarne Lehmann Weng

GLADSAXE KOMMUNE
Postbud Kaj Bruhn Andersen
Redaktør Ole Andersen
Husholdningslærer Kirsten Beck
Lærer Lauge Dalgård
Skolebetjent Tage Hansen, best.medlem
Fabrikant Otto Marcussen
Lærer Lars Nielsen

GLOSTRUP KOMMUNE
Forretningsfører Børge Jansbøl
Direktør Leo Lollike
Borgmester Martin Nielsen,
bestyrelsens næstformand
Bygningssnedker Bent Wolff

HERLEV KOMMUNE
Borgmester Ib Juul
Ingeniør Erik Breith
Afdelingsgeolog Henning Kristiansen,
bestyrelsesmedlem
Kommunalbestyrelsesmedlem Hans Ohlsen

KØBENHAVNS KOMMUNE
Forretningsfører Andreas E. Hansen
Kontorchef H. Thustrup Hansen
Overlærer Niels Jørgen Hougaard
Typograf Kurt Kristensen
Borgmester Lilly Helveg Petersen
Borgerrepræsentant Gunnar Ulbæk,
bestyrelsesmedlem
Overborgmester Egon Weidekamp

LEDØJE-SMØRUM KOMMUNE
Borgmester Eigil Paulsen, best.medlem
Salgschef Ib Petersen

LYNGBY-TAARBÆK KOMMUNE
Ekspeditionssekretær Carlo Hansen
Borgmester Ole Harkjær
Typograf Vivi Henriksen
Fagforeningsformand Birgil Cort Jensen
Civilingeniør Palle Løvdal
Direktør Kaj Kramer Mikkelsen,
bestyrelsesmedlem
Cand. polit. Inge Schjødt

RØDOVRE KOMMUNE
Direktør Chr. Helmer Jørgensen
Typograf Ebbe Kristensen
Grosserer Tage Nielsen
Advokat Bent Osborg, best.medlem
Lagerarbejder Hans Rasmussen

VÆRLØSE KOMMUNE
Kommunalbestyrelsesmedlem
Nette Holmboe Bang
Kommunalbestyrelsesmedlem
Elo Christensen
Borgmester E. Ellgaard, best.medlem

FIGURE 15-61. ANNUAL GENERAL MEETING PARTICIPANTS

Each participating municipality choses one member to the mangement irrespective of the size of the municipality.

The management consists of 12 members and the chairman and vice chairman are chosen by the management. This method of election will ensure full representation from the smaller municipalities.

The municipalities which have a contract with the Incinerator plant of more than 10 years are admitted in the management as observers.

The management holds a meeting regularly on the 2nd Monday of each month and the meetings are planned for a complete year at a time.

The permanent members of the management receive a minor fee, the chairman and the vice chairman a somewhat larger fee. The fee is prepaid each month.

Board of Directors

The daily leadership of the incinerator plant is handled by one director who is assited by one operational manager (technical), one office manager (administrative), as well as one technical adviser (research field).

Members of the Staff

In total is employed 61 staff members (1978) at the plant, including above mentioned staff. The plant operates in three (3) shifts during 24 hours and four (4) members are on each shift.

Technical Group

In order to coordinate the refuse treatment with the collection sector there has been established a technical group made up of the engineers of the participating municipalities as well as the management of West Incinerator.

Meetings are held every second month, whereby a considerable contact between the environmental work in the municipalities and the West Incinerator is maintained.

Personnel

Details of the job title, shift, hours/day, days/week, and duties are shown below:

- Administration - 1 shift = 8 hours/day, 5 days/week
  - 1 managing director (part-time)
  - 1 technical consultant
  - 1 plant manager
- Bookkeeping - 1 shift = 8 hours/day
  - 1 manager
  - 1 bookkeeper/cashier
  - 1 clerk (telephone attendant/typewriting)
  - 1 clerk, (part-time) (typewriting)
  - 1 office boy
- Cleaning - 1 shift = 8 hours/day, 7 days/week
  - 2 women for cleaning offices and canteen.
- Refuse cranes - 3 shifts = 24 hours/day, 7 days/week
  - 3 crane operators
  - 2 reserve operators for holidays, vacations, and sickness. One of the operators will always be free as each operator has 8 extra free hours (1 day) for each 40 hours work. The other reserve operator works half a day with the reserve crane cleaning the silo entrance ports and half day for cleaning and removing the clinkers in the ash silo.
  - 1 reserve operator (day time) for lubricating and cleaning. (This reserve will be in full work as soon as more than two crane operators are free and on sick leave).

- Ash cranes - 1 shift = 8 hours/day, 5 days/week
  - (One reserve operator from the refuse crane will help cleaning the silo in the afternoons.) The crane operator is free on Saturdays and Sundays.
- Control Room, Furnaces, and Boilers - 3 shifts = 24 hours/day, 7 days/week
  - 3 foremen. Their duties are to sample the water for the boilers, start for testing the emergency generator, control the water on the air conditioning system, control level of hot water tank and changing (repair) of instruments.
  - 3 boiler attendants. These attendants take care of the boiler and help the foremen with their duties.
  - 3 furnace attendants. These attendants watch the furnace and equipment, clean the boilers and take care of general cleaning in the plant.
  - 3 reserve foremen
  - 3 reserve boiler attendants
  - 3 reserve furnace attendants. The reserve crew is used for sick leave, vacation, and free days, and when not in full use help the duty crew with their duties.
- Workshop - 1 shift = 8 hours/day, 5 days/week
  - 1 foreman
  - 2 electricians
  - 6 artisans
- Cleaning - 1 shift = 8 hours/day, 5 days/week
  - 3 unskilled workers. These workers help in the workshop and the plant in general and take care of the general cleaning
- Weighing Bridge - 2 shifts = 16 hours/day
  - 3 attendants. The first attendant works from 6:00 a.m. to 12:30 p.m. The second attendant works from 12:30 p.m. to 9:00 p.m. The third attendant works from 8:00 a.m. to 4:00 p.m. The third attendant will be on the first

or the second shift in case of sick leave or vacations. Every third week-end one of the attendants is on duty, Saturdays from 6:00 a.m. to 3:00 p.m. and Sunday from 6:00 a.m. to 3:00 p.m.

- Refuse Reception Hall - 1 shift = 8 hours/day, 5 days/week
  - 1 unskilled worker. Directs the traffic in the hall, taking care that no large pieces of iron or similar are discharged into the refuse silo.
- Refuse Crusher - 1 shift = 8 hours/day, 5 days/week
  - 1 unskilled worker. Operates the crusher.
- Ash Disposal
  - For this purpose, the plant contracts a lorry with driver for transport of the ashes to a close-by disposal area.

Training (Education and Experience)

When staffing the plant, education and experiences are desired as listed below:

- Managing Director
  - The title should explain the qualifications required to manage the plant
  - The managing director is only employed part-time as the plant has a technical consultant who takes care of the daily problems.
- Technical Consultant
  - Mechanical Engineer degree of the equivalent
- Bookkeepers
  - The personnel is defined by the degrees indicated and positions held
- Crane Operators
  - Artisan or unskilled worker trained at the plant
- Foreman
  - Engineer (marit.) with electrical installation.

- Boiler Attendant
  - With official certificate as boiler attendant
- Furnace Attendant
  - Artisan or unskilled worker trained at the plant
- Electrician
  - Qualified as electrician
- Weighing Bridge Attendant
  - Clerk training as the jobs require checking of accounts and other administration work.

ECONOMICS

The establishment of the incinerator plant was based on two main economic principles:

1. There has been created capacity for each partnership municipality on the prognosis of population development and a capacity investment on this basis. (Initial Capital Investment)
2. Each partnership municipality contributes according to the degree of utilization, i.e., payment by weight. (Annual Costs of Operations, Maintenance and Amortization)

Capital Cost

The original three-furnace complete plant cost 140,580,222 Dkr in 1969-1970. With the addition of the fourth unit in 1975-1976 and some other items as outlined in Table 15-8, the grand total capital investment cost is 204,972,634 Dkr. This table shows the capital investment cost distributed both by assets and liabilites.

Annual Costs and Revenues

Table 15-9 is also a "balance of annual expenses and annual revenues". By definition of "not-for-profit organization", the expenses must equal revenues. In this case, they are equal to 41,908,696 Dkr. These revenues come from various sources. The newer figures from the 1975/76 period are shown in Figure 15-9.

Citizens of Partnership Municipalities

Citizens pay in two ways: (1) per person and (2) per ton. In 1974/75 the results were"

A - Charge per person 30 D.kr. $5.07/person

(add to this)

B - Charge per tonne 35 D.kr. $5.92/ton

Hnece one might calculate for himself as follows:

TABLE 15-8. CAPITAL COST (ASSETS AND LIABILITIES) AT COPENHAGEN: WEST (FISCAL YEAR 1975-1976)

Assets	D.kr.	Liabilities	D.kr.
Reserve amount held in quick asset form to pay for the establishment of a fourth furnace, district heating plant, and for the coverage of cost outlays	50,013,257	The amounts, which are free from part-payment until 1979/1980 are subject to an annual interest of 8 percent, and the debt of West incineration to these townships, on March 31, 1976	24,071,789
Amount due from townships, and other debtors	2,880,171	Outside capitals from various creditors amount on March 31, 1976	106,365,615
Storeroom material, oil and cafeteria material	254,203	Amount concerning guarantees with enterprises (sureties)	2,480,581
Fixed plant in place	140,580,022	Difference between the face value and the quoted value (? market value) of obligation bought	12,672,616
Expenses (?)	16,224	SUBTOTAL	145,590,601
Sum of part to establish a slag landfill at Vestskoven	1,864,009	Amount (variance creditors other than West incineration; that is, tax to the source from staff members, due vacation compensation, etc.)	506,758
Preliminary investigations for the establishment of a dumping ground at Vestskoven	44,552	Current account with customs concerning (name ?)	2,270,282
Sum paid out for the fourth furnace	2,077,213	Area of expenses	10,303,313
Sum paid for the second crusher	1,436,420	Creditors	13,080,353
Investment sum for the transfer station of Hillerod, where West incineration, as agreed, has established the machine plant as well as different other lesser installation operations	132,365	Investments (or sums placed aside)	6,577,225
Investment sums for the establishment of district heating plants to Ll. Birkholm, etc., on March 31, 1976	5,674,198	Township Capitals	39,724,455
TOTAL ASSETS	204,972,634	TOTAL LIABILITIES	204,972,634

TABLE 15-9 EXPENSE AND REVENUE BALANCE AT COPENHAGEN: WEST

Expenses	D.kr.	Revenues	D.kr.
Operating personnel cost	4,766,827	Communities (12) tax based on tonnes disposed	7,739,726
Electricity	1,997,539	Other waste disposal fees (institutions, private haulers, industry)	2,029,734
Materials	100,165	Communities (12) tax based on population	17,279,800
Cooling water	141,348	District heating revenue	10,106,526
Canteen	178,738	Sale of sorted materials	219,300
Other utilities	29,501	Tipping fee at old landfill	370,660
Ash recovery and disposal	1,082,522	Interest earned*	3,855,745
Expense to operate Vorloes landfill	127,275	Other revenues	188,127
Research	315,324		
Expenses of assembly and board of directors	210,411		
Salary of eight-nine administrators	667,721		
Office supplies	475,011		
Maintenance costs (8 Kr/tonne)	1,614,145		
Property taxes and insurance	1,000,264		
Expenses of running the district heating network and the standby boiler	1,262,600		
Depreciation of district heating network	1,400,000		
Interest on loan made by Gentofte, Lyngby-Taarbaek	1,925,743		
Interest on loan made by Glostrup and Ballerup for construction of four furnaces	86,400		
Paid for foreign (?) capital	7,305,954		
Part-payment of the corresponding sum, the following is paid (?)	11,453,037		
Other expenses, West incineration part pension to staff members, from the Gentofte township	34,814		
The following sum is put aside for the partial financing of expenses to the case of lesser installation work	5,426,307		
TOTAL EXPENSES	41,809,696	TOTAL REVENUES	41,809,696

* On the basis of the difference between the time for the payment of plant expenses and the payment of the loan proceeds, West has earned interest.

$$\text{Persond Charge} = \frac{\$5.07}{\text{Person Year}} + \frac{\$5.92}{1000\text{ kg}} \qquad \frac{315\text{ kg}}{\text{Person-Year}}$$

$$= \$5.07 + \$1.87$$
$$= \$6.94 \text{ per person per year}$$

This equals to about $20.03 revenue per ton from citizens. This figure might also be defined as the net disposal fee for the household refuse portion of the total waste stream.

Citizens of Non-Partnership Municipalities

Presently non-partnership municipalites pay 45 D.Kr. per tonne ($7.08 per ton), but no additional head tax. After five years, this can be renegotiated. When refuse from nomal partners rises, the non-partners will have to find other disposal means. The effect of the total effective charge to non-partners being lower than for partners is to encourage more waste in early years and thus more fixed expenses are covered.

Industries and Private Haulers

In a similar manner industries and private haulers are charged only $45 D.Kr. per tonne ($7.08 per ton). This policy towards the industry of the management of West Incinerator is an initiative to improve environment of the society, the industries hereby are motivated not to dump the refuse in the open.

Citizens Bringing Refuse in Private Cars and Trailers

Any citizen driving his own vehicle can bring refuse to the refuse treatment plant at no charge. He may offload his material and place it in any of the segregated bins, i.e., ferrous in one bin, mixed color glass in another bin, cardboard in yet another and finally mixed refuse to be burned in another bin.

Sale of Energy to the District Heating Network

During the 1974/75 heating season, hot water was sold for 32 D.Kr. per tonne ($5.02 per ton). This figure has risen substantially since then.

Profitableness at Exploitation of Heat

For the final time, Mr. Blach's comments are entered into the American record. This presents the economics of a 3 x 12 t/h plant versus a 2 x 3 t/hr plant. The analysis uses three different Kcal/kg estimates and two utilization rates.

> "As mentioned before, the cost of the installation of a boiler for the recovery of the waste heat can be expected to be of the same magnitude as the cost of other forms of installation for the cooling of the flue gas. In the same way, the operational and maintenance costs can be calculated to be of the same magnitude provided the boiler construction is executed correctly and appropriately, taking into considering the special corrosive, wearing, and clogging properties of the flue gas.
>
> As previously mentioned, the income from the waste heat sales will be a real operational income which can cover a larger or

smaller part of the operational costs, depending on how large an amount of the produced heat can be sold and at which price. The following enclosed two tables (Tables 15-10 and 15-11) show examples of operational costs (exclusive of interest and decpreciation) and incomes resulting from heat sales from a large plant with three units of 12 t/h and a smaller plant with three units of 3 t/h, calculated for net calorific values of 1,500, 2,000, and 25,000 Kcal/kg and with an effectivity of burning capacity for the smaller plant for 50 percent and 75 percent, respectively, and for the larger plant 65 percent and 80 percent, respectively, of the nominal capacity. As a total sale of the produced heat all the year round cannot normally be expected, there has only be calculated the incomes deriving from sales of 75 percent of the produced heat.

The obtainable selling price for the heat--here rated to Dan.kr. 20, -per million Kcal--will be determined by the fact that it should be able to compete with the production price for a normal oil-fired plant, i.e., among other things, it will be dependent on the price of oil. When in competition with heat from power stations, the selling price is lower (Dan.kr. 12,--15,--per million Kcal).

As shown on the tables, the incineration capacity (line 1) and operational costs (line 6) are equally rated for the different calorific values. This, of course, is an approximation, but nevertheless close to the real figures as far as the operational costs are concerned, which will increase only little with the increase of the calorific value, whereas the incineration capacity may vary with the calorific value, depending on the refuse composition, so that the capacity can normally be expected to increase for lower calorific powers. This means that the values for the operational costs per ton refuse incinerated

TABLE 15-10. OPERATIONAL COSTS (EXCLUSIVE OF INTEREST AND DEPRECIATION) AND INCOME BY HEAT SALE FROM A PLANT WITH THREE FURNACES OF 12 t/h FOR VARIABLE NET CALORIFIC VALUES OF REFUSE AND DEGREE OF INCINERATION CAPACITY

Plant capacity: 3 x 12 t/h Theoric nominal max. capacity: 3 x 12 x 24 x 365 = 315.360 t/year	Net Calorific Value, Hg					
	1,500 Kcal/kg		2,000 Kcal/kg		2,500 Kcal/kg	
	Degree of Utilization					
	65%	80%	65%	80%	65%	80%
1. Effective incinerator capacity (t/year)	205.000	252.300	205.000	252.300	205.000	252.300
2. Produced heat at 65% effectivity (Kcalx10^6/year)	199.900	246.000	266.500	328.000	333.150	410.000
3. Presumably sold heat (75%)	150.000	184.500	199.900	246.000	249.900	307.500
4. Income by heat sale at presumably 20,-Dan.kr/ 10^6Kcal (Dan.kr./year)	2.998.200	3.689.900	3.997.500	4.919.900	4.996.900	6.149.300
5. Do. (4:1) (Dan.kr/t)	14.70	14.70	19.50	19.50	24.40	24.40
6. Calculated operational costs (exci. interest and depreciation) (Dan.kr/year	6.400.000	7.300.000	6.400.000	7.300.000	6.400.000	7.300.000
7. Do. (6:1) (Dan.kr/year)	31.50	29.00	31.50	29.00	31.50	29.00
8. Operational costs-heat sale (6-4) (Dan.kr/year)	3.401.880	3.610.112	2.402.500	2.380.150	1.403.120	1,150.200
9. Do. (7-5) (Dan.kr/year)	16.60	14.30	11.80	9.50	7.00	4.60

TABLE 15-11. OPERATIONAL COSTS (EXCLUSIVE OF INTEREST AND DEPRECIATION) AND INCOME BY HEAT SALE FROM A PLANT WITH TWO FURNACES OF 3 t/h FOR VARIABLE NET CALORIFIC VALUES OF REFUSE AND DEGREE OF INCINERATION CAPACITY

Plant Capacity: 2 x 3 t/h Theoric nominal max. capacity: 2 x 3 x 24 x 365 = 52.560 t/year	Net Calorific Value, Hg					
	1,500 Kcal/kg		2,000 Kcal/kg		2,500 Kcal/kg	
	Degree of Utilization					
	50%	75%	50%	75%	50%	75%
1. Effective incinerator capacity (t/year)	26.280	39.420	26.280	39.420	26.280	39.420
2. Produced heat at 65% effectivity (Kcalx10^6/year)	25.700	39,500	34,200	51,300	42,800	64.100
3. Presumably sold heat (75%)	19.300	28.900	25.700	39.500	32.100	49.100
4. Income by heat sale at presumably 20,-Dan.kr/ 10^{6}Kcal (Dan.kr./year)	384.400	576.600	512.500	768,700	640.600	960.900
5. Do. (4:1) (Dan.kr/t)	14.70	14.70	19,50	19.50	24.40	24.40
6. Calculated operational costs (exci. interest and depreciation) (Dan.kr/year)	1.100.000	1,570.000	1.100.000	1.570.000	1.100.000	1.570.000
7. Do. (6:1) (Dan.kr/year)	42.00	40.00	42.00	40.00	42.00	40.00
9. Operational costs-heat sale (6-4) (Dan.kr/year)	752.000	993.500	587,000	801,300	459,500	609,200
9. Do. (7-5) (Dan.kr/year)	27.30	25.30	22.50	20.50	17.60	14.60

can be expected to be proportionately lower for the refuse with the lower calorific value than for the refuse with the high calorific value.

As regards the small plant, there has been calculated with two-shift operation at 50 percent exploitation and three-shift operation at 75 percent exploitation, and the plant closed on Saturdays and Sundays. For the larger plant, calculations are based on continuous operation all days of the year.

It can be seen that the operational costs per burnt ton of refuse (line 7) are much cheaper for the large plant than for the smaller one. The operational costs for the small plant executed as grate furnace and with mechanical gas cleaning, and for the large plant executed as grate/rotary kiln furnace with electrostatic precipitator, will be almost equal per ton of plant capacity. With uniformly rated interest and depreciation conditions, the large plant will consequently also have the lower total operational costs per treated ton of refuse.

Accordingly, with the large plant, a more effective and secure refuse treatment, a better gas cleaning as well as a cheaper treatment price are achieved."

FINANCE

The financial arrangements were straightforward. The 12 municipalities based on population put in 25,000,000 D.Kr.. The remaining 115,000,000 D.Kr. ($16,284,000) was borrowed at local banks. The payoff period is variable as well as the interest rate that has averaged about 8 percent. The investment contribution from the partnership municipalities is not paid back and does not accummulate interest. However, the investment can be increased or decreased by working profits or deficits.

TABLE 15-16. CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
feet	meters	0.3048	meters	feet	3.281
square feet	square meters	0.0929	square meters	square feet	10.76
cubic feet	cubic meters	0.0283	cubic meters	cubic feet	35.31
inches	millimeters	25.4	millimeters	inches	0.0394
cubic yards	cubic meters	0.7646	cubic meters	cubic yards	1.308
barrels (oil)	cubic meters	0.15899	cubic meters	barrels (oil)	6.290
miles	kilometers	1.609	kilometers	miles	0.6214
square miles	square kilometers	2.589	square kilometers	square miles	0.3861
acres	square kilometers	0.004047	square kilometers	acres	247.1
acres	hectares	0.4047	hectares	acres	2.471
gallons	cubic meters	0.003785	cubic meters	gallons	264.2
ton (short)	tonne (metric)	0.9078	tonne (metric)	ton (short)	1.102
pounds	grams	454	grams	pounds	0.002046
grams	grams	0.0648	grams	grams	15.42

TABLE 15-16. CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiple by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu	kilowatt-hours	0.00029307	kilowatt-hours	Btu	3413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds	grams per cu meter	1.205	grams per cu meter	pounds per 1000 pounds	0.93
grams per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grams per cu ft (68 F)	0.43

TABLE 15-16.

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2	nanograms per Joule	pounds per million Btu	0.0023
pounds per million Btu	milligrams per megajoule	499.2	milligrams per megajoule	pounds per million Btu	0.00233
cubic feet per minute	cubic meters per hour	1.699	cubic meters per hour	cubic feet per minute	0.588
gallons per minute	liters per minute	3.785	liters per minute	gallons per minute	0.004
pounds per square inch	kilograms per square meter	4.882	kilograms per square meter	pounds per square inch	0.204
pounds per square inch	atmospheres	0.0004725	atmospheres	pounds per square inch	14.69
pounds per square inch	newtons per square meter	6894.8	newtons per square meter	pounds per square inch	0.00014
pounds per square inch	kilopascals	6,8948	kilopascals	pounds per square inch	0.1450
atmospheres	bars	1.0133	bars	atmospheres	0.9869
atmospheres	kilopascals	101.3	kilopascals	atmospheres	0.0098
pounds per square inch	bars	0.06895	bars	pounds per square inch	14.50

TABLE 15-17. EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES, (NATIONAL MONETARY UNIT PER U.S. DOLLAR) 1948 TO FEBRUARY, 1978[a]

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

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